Nuclear Power

The journal of British nuclear engineering

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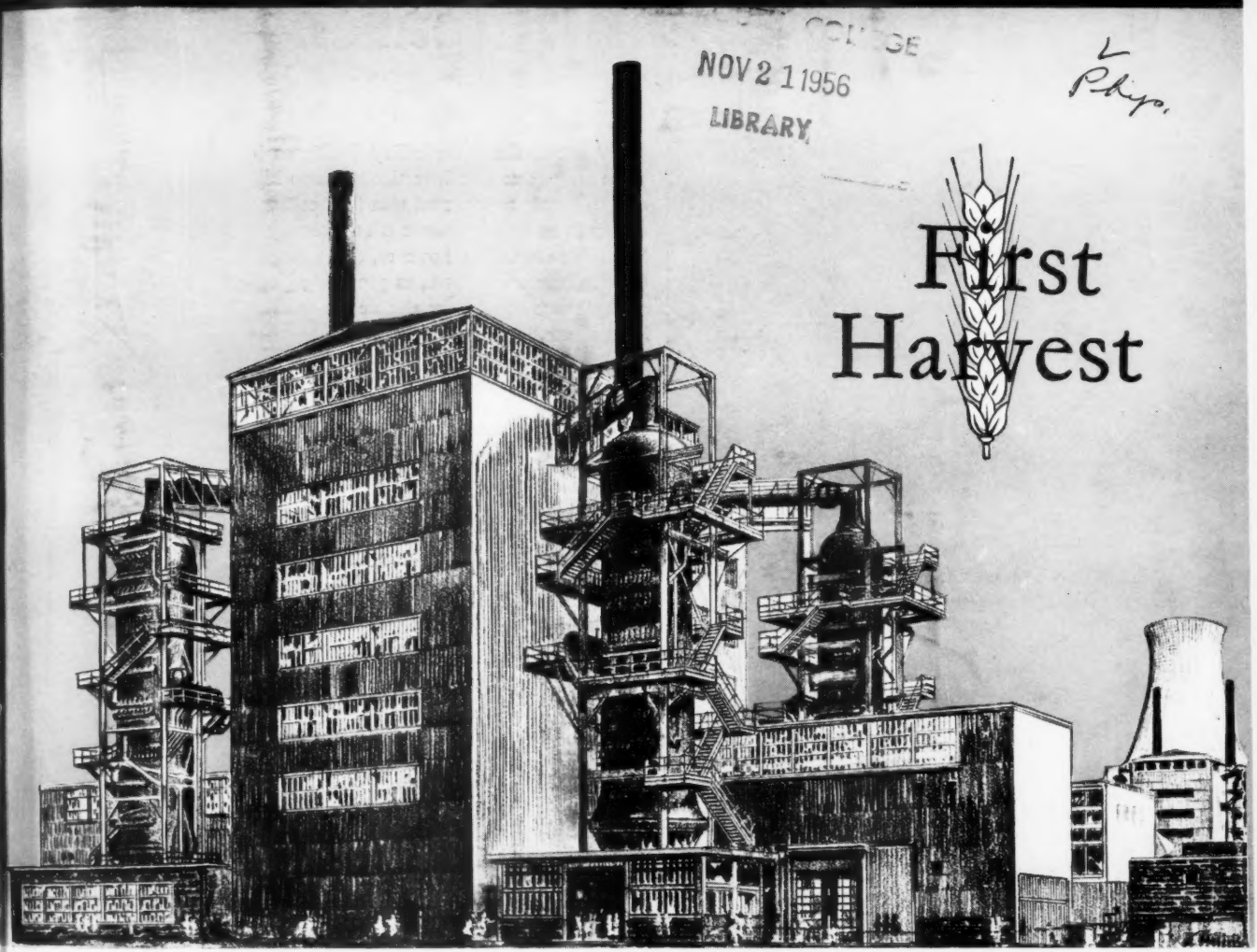

Since he first probed the secrets of the atom, man has pursued the vision of using its enormous forces for practical power production. Ideas in the minds of scientist and engineer were the seeds that have now come to fruition with the opening of Calder Hall, the world's first full-scale atomic power station. The contribution of Babcock and Wilcox Ltd. to this remarkable achievement started eight years ago when, at the request of the Government, they undertook the design study of steam-raising plant for nuclear power stations. They have since manufactured and installed all the special 80-feet-high steam-generating towers for Calder Hall and are extensively engaged in other important developments which offer to the nation a sure promise of greater harvests in the field of atomic power.

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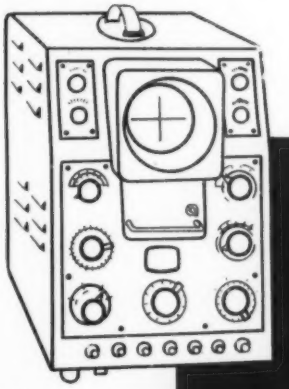
November 1956 volume I number VII 3s 6d

Cossor Oscillographs in research



The value of the Cathode Ray Oscillograph as an aid to scientific investigation is so high and so widely appreciated that further emphasis on its importance is unnecessary. We *would* emphasise, however, that Cossor Instruments Ltd., in providing a wide range of these invaluable instruments, have been able to help Research with the solution of many of its difficult problems and are anxious to place their long experience of the subject at the disposal of enquirers.

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Double Beam Oscillograph

Two independent amplifiers with frequency ranges 20 c/s to 7 Mc/s and 20 c/s to 100 Kc/s. The 4-in dia. flat screen tube operates at 2 kV. Time intervals and Input Voltages may be measured on either beam by means of the calibrated controls. Time base for repetitive, triggered or single-stroke scan with velocity 150 milliseconds to 15 micro-seconds.

The instrument in operation near the face of the British Experimental Pile "BEPO" at the Harwell Research Establishment of the United Kingdom Atomic Energy Authority.

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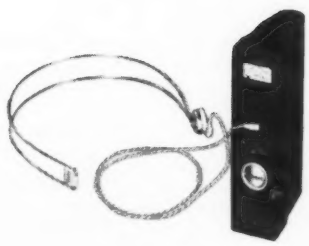
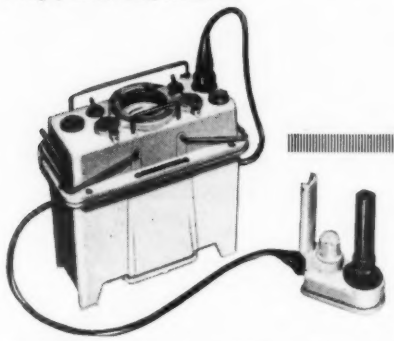
HEALTH INSTRUMENTATION BY **PHILIPS**

The units illustrated here are selected from Philips range of monitoring equipment designed to safeguard the health of workers in atomic factories and research establishments. Full details will gladly be sent on request.

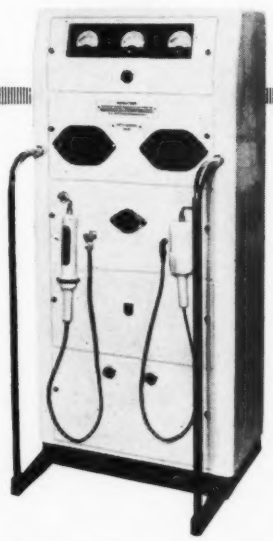
Philips, with their many years' experience in the field of radiation measurement, are best qualified to advise on all health instrumentation problems.



Pocket Battery Monitor type PW 4010. Sensitive to gamma rays, high energy beta radiation and X-rays, with ranges for high and low sensitivity. Low intensities also audibly detectable by earphones. Ideal for intensity measurements in laboratories, checking radio-active sources or tracers, etc. *A product of N.V. Philips, Eindhoven, Holland.*



Contamination Meter type 1092D. Accurately measures gamma activity on clothing, benches, etc. Interchangeable power supply units : high tension battery, mains unit, or vibrator. Cold cathode valves throughout obviate need for filament heating and help to reduce size, weight and maintenance. *Developed in conjunction with U.K.A.E.A., Harwell.*



A number of these monitors have been supplied to Calder Hall

Hand and Clothing Monitor type 1404A. Enables workers to rapidly check their hands and clothing for harmful contamination. The instrument incorporates hand units for detecting beta-gamma radiation and, below these, two frisking probes for checking the clothing for beta-gamma and alpha radiation. Special care has been taken in design to ensure ease of cleaning and quick replacement of contaminated parts. *Developed in conjunction with U.K.A.E.A., Harwell.*

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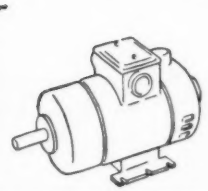

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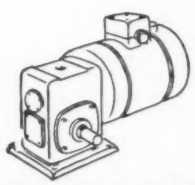

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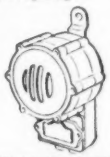

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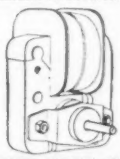

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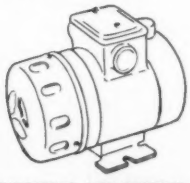

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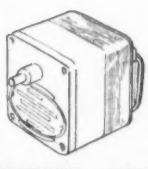

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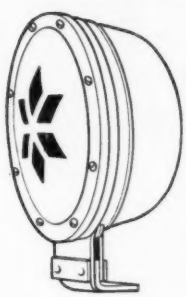

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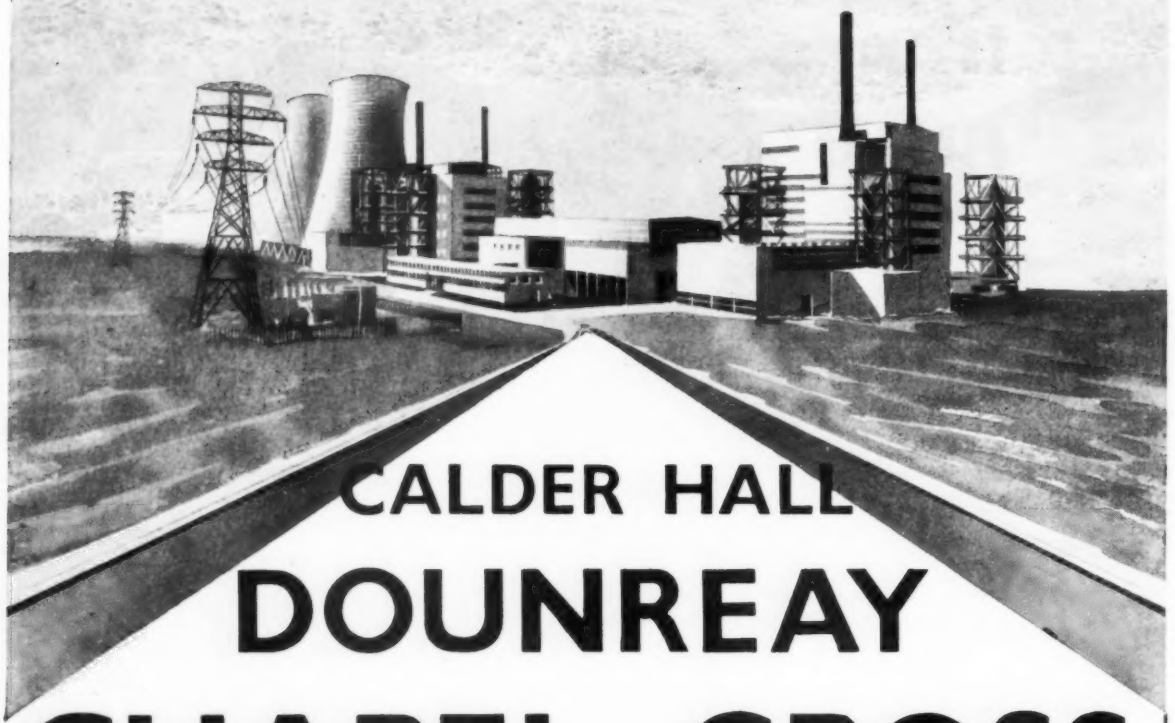

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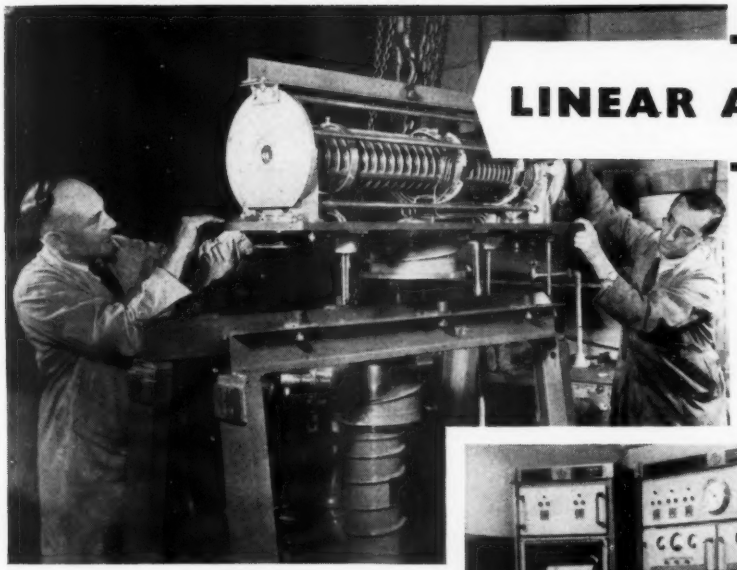
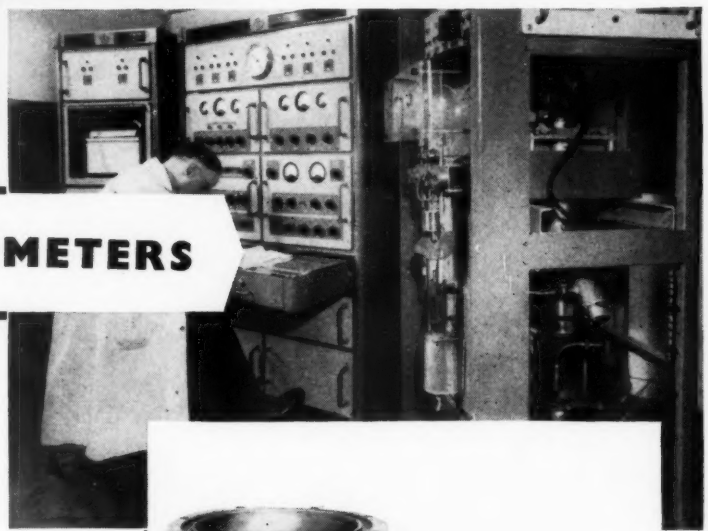


LINEAR ACCELERATORS

Assembling a 25-MeV electron linear accelerator for A.E.R.E., Harwell, at the Trafford Park Works.



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An MS2 mass spectrometer in use at Harwell.

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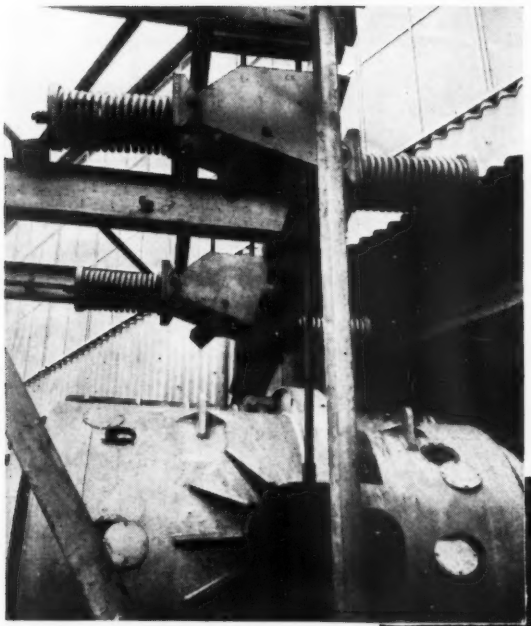

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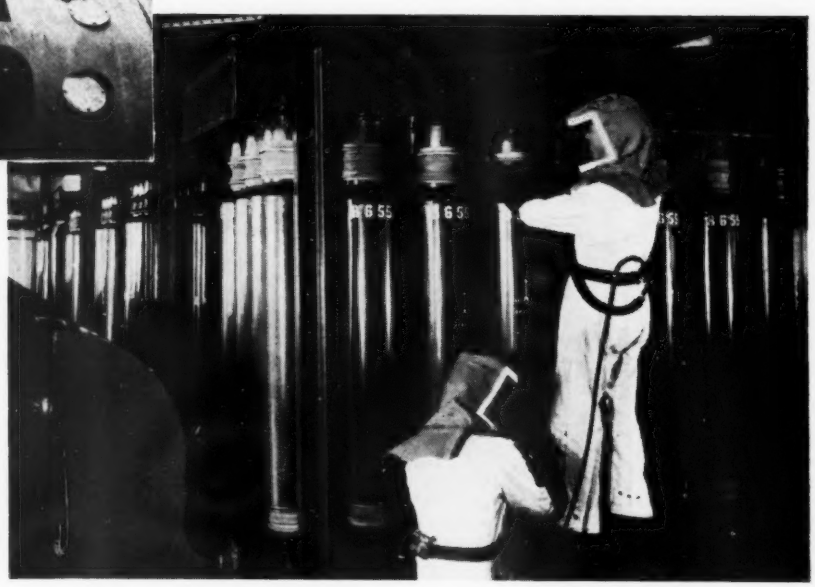

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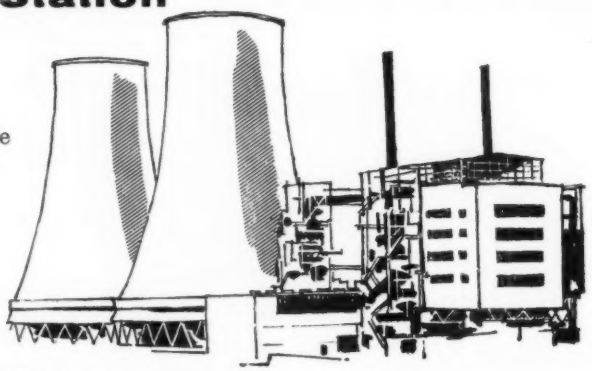

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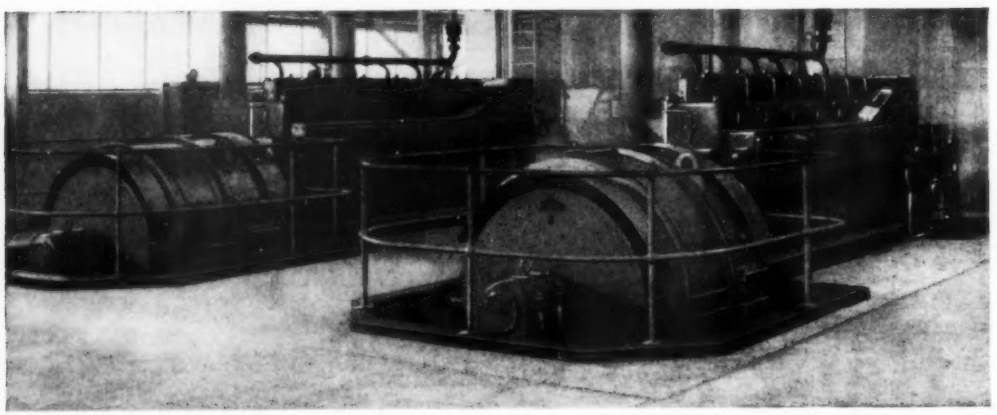

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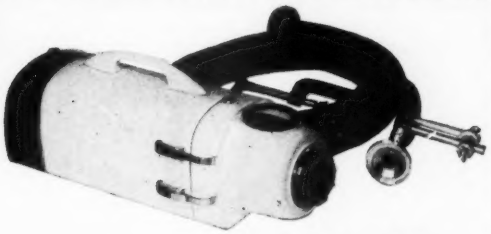

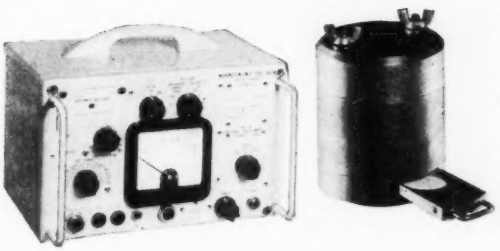

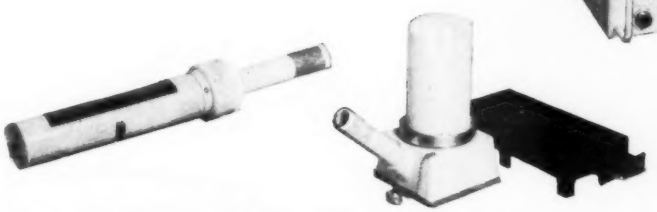

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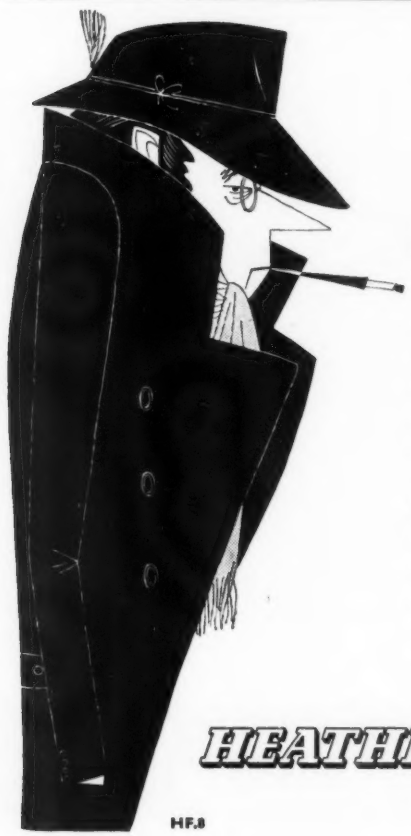

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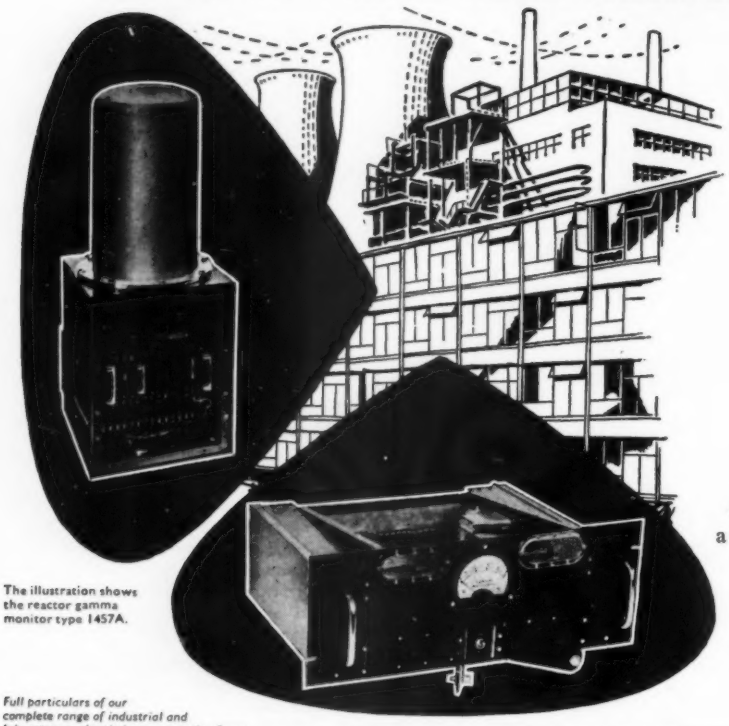
Calder Hall uses I.D.L. Nucleonic Instrumentation



The illustration shows the reactor gamma monitor type 1457A.

Isotope Developments Limited, as specialists in the industrial and research application of atomic energy, are playing a part in the instrumentation of the Calder Hall Power Reactor.

Besides specific instruments for Calder Hall, Isotope Developments are engaged upon an extensive programme of commercial reactor instrumentation. Amongst their present projects are the Nucleonic instrumentation of the "Merlin" (Medium Energy Research Light Water Moderated Industrial Nuclear Reactor) experimental reactor produced by the A.E.I. John Thompson Nuclear Energy Co. Ltd., and acting as consultants and suppliers of instruments for a number of European and overseas reactors.

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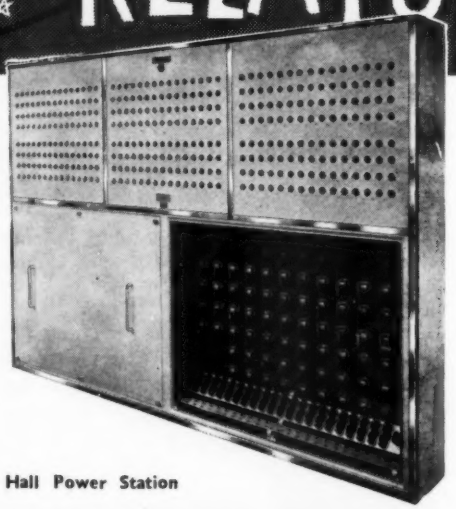
alarm circuit

RELAYS



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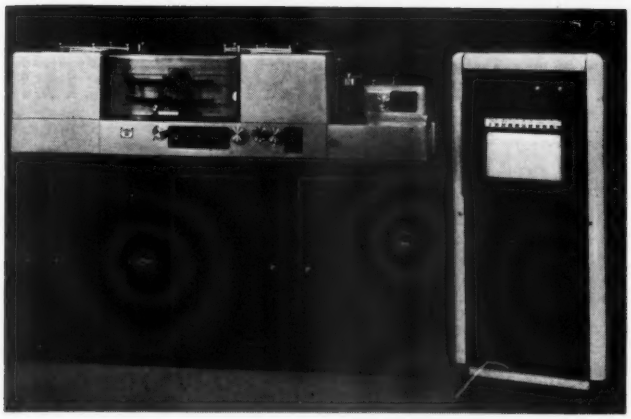

the H800 infra-red spectrophotometer

This instrument is the most advanced of its kind for all forms of qualitative and quantitative analysis. It produces a pen-written record showing directly the spectra of the substance being tested. Prisms of glass, quartz, lithium fluoride, calcium fluoride, rocksalt, potassium bromide, and caesium bromide are available and are interchangeable either one with another or with a diffraction grating. The instrument can be used either for double beam or single beam work and the resolution is high even at fast scanning speeds.

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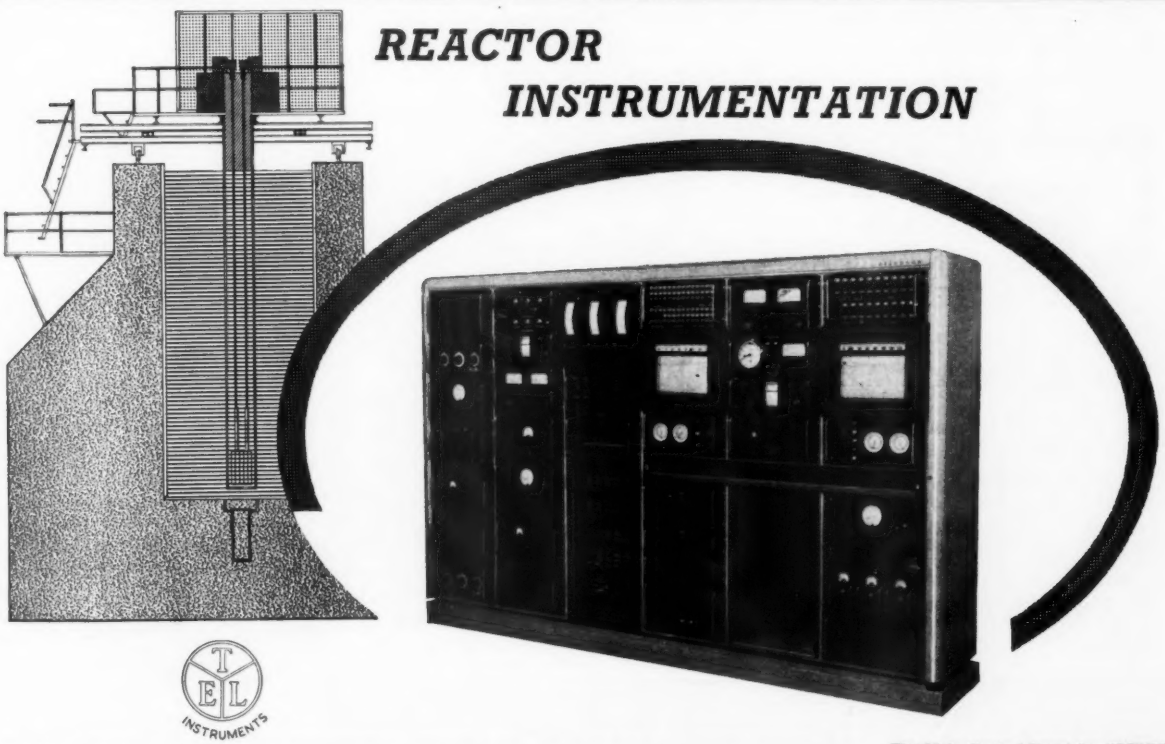

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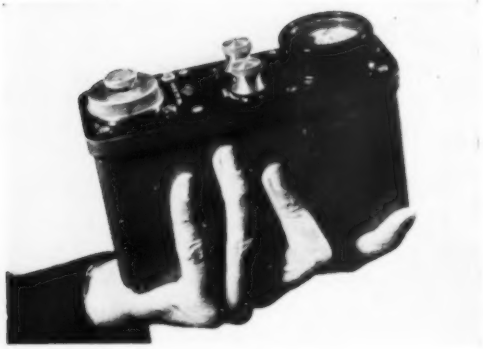

RADIATION MONITOR TYPE T.R.56

This robust self-contained instrument uses as a detector a large gamma geiger counter with a 2" moving coil meter for visual indication. This meter is calibrated in two ranges, 0–0.5 and 0–5 mR/HR. A small two pin socket is provided for headphone use. The Panax T.R. 56 Monitor is designed to the most rigid specification and constructed to withstand rough handling. Its steel case is completely sealed and batteries are housed in a separate waterproof compartment. Transistors are used exclusively in this instrument, power being derived from two 1·5V type U2 cells arranged in series. Instrument dimensions are 7½" x 2½" x 5½", weight 3¼ lbs. Battery life exceeds 500 hours. Temperature compensated up to 55°C.

Other types of Panax instruments in the field of Isotope application include a double pulse generator (type 100A), high speed scaler (type 100C), rate meter (type 5054), universal lead castle (type ULC), dekatron scaler (type D554) and power pack (type 3,000).

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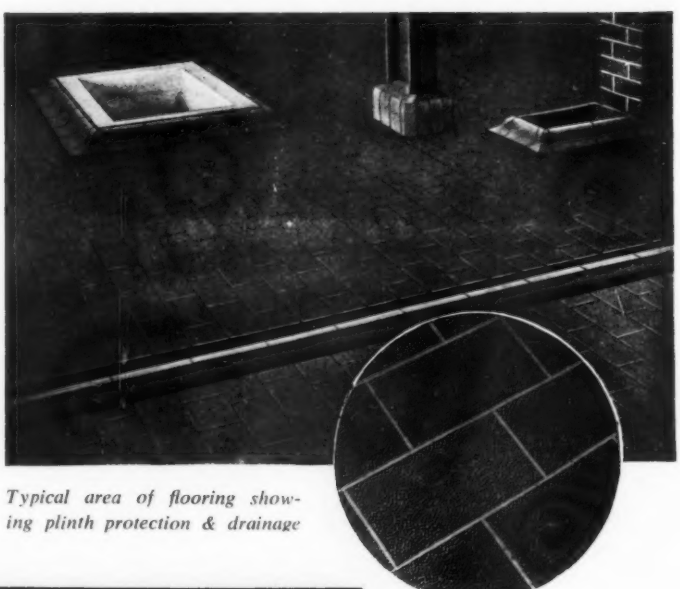

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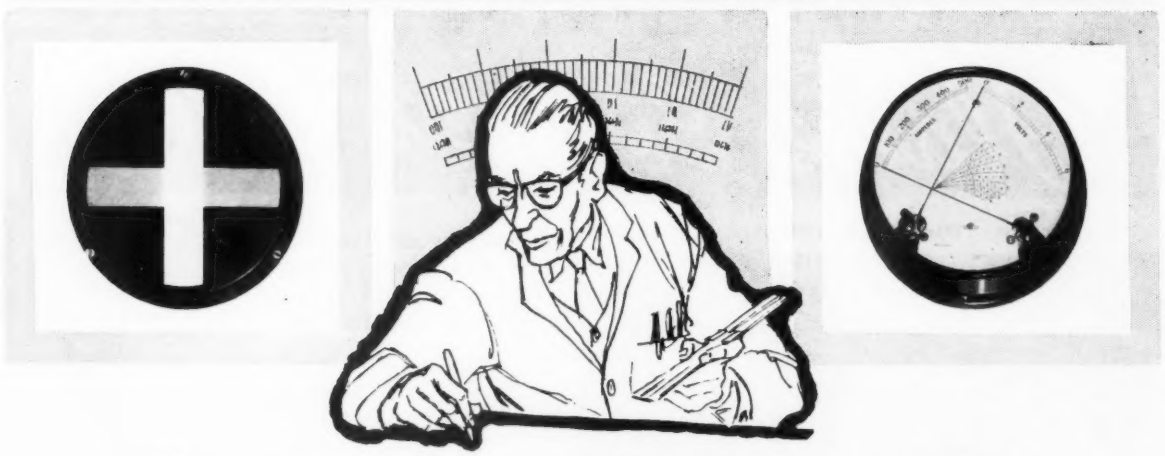

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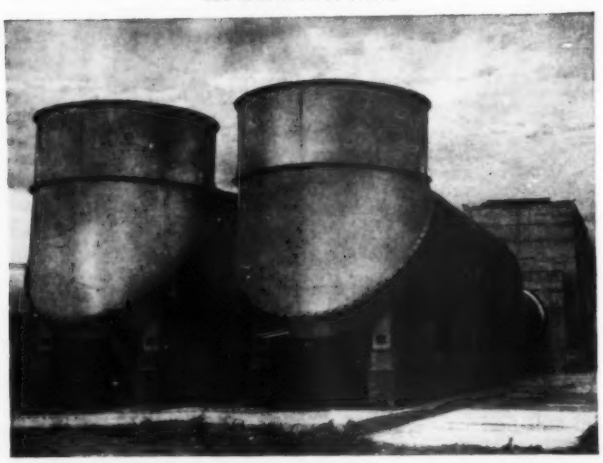

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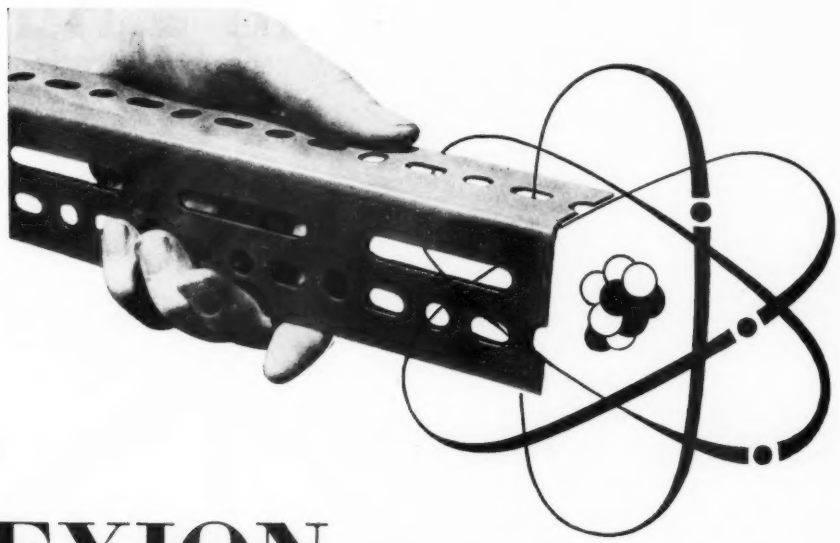

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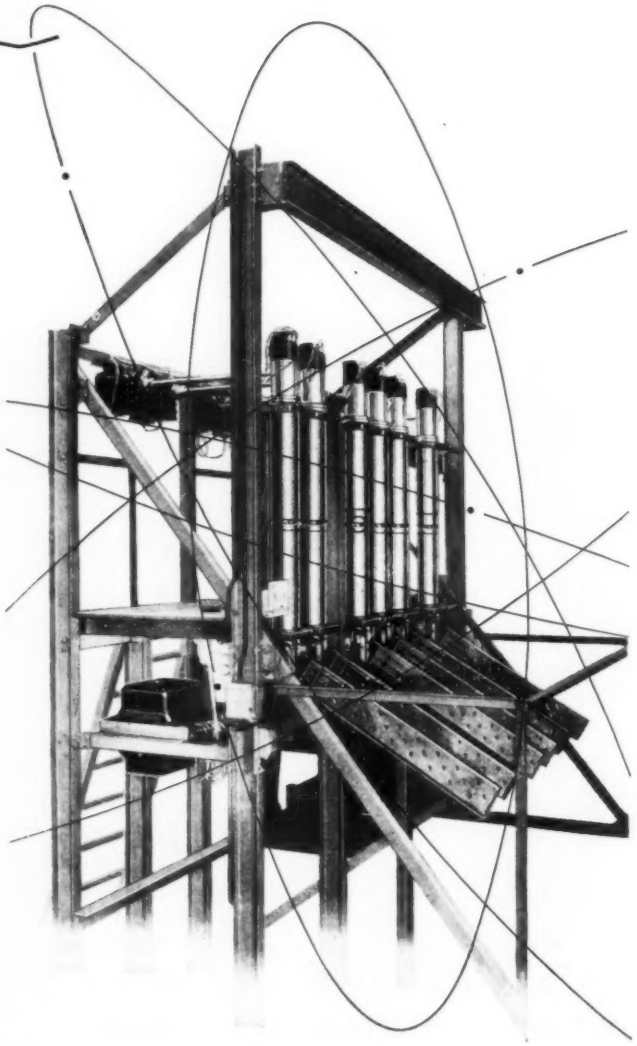

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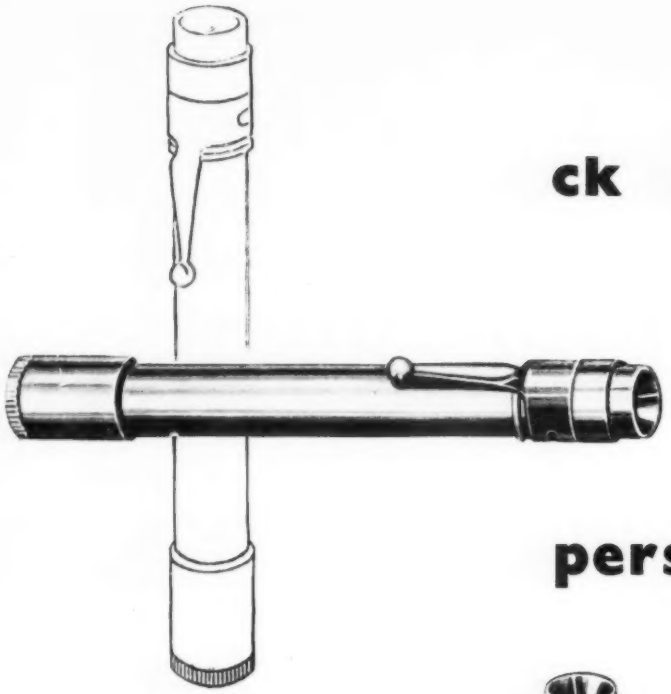

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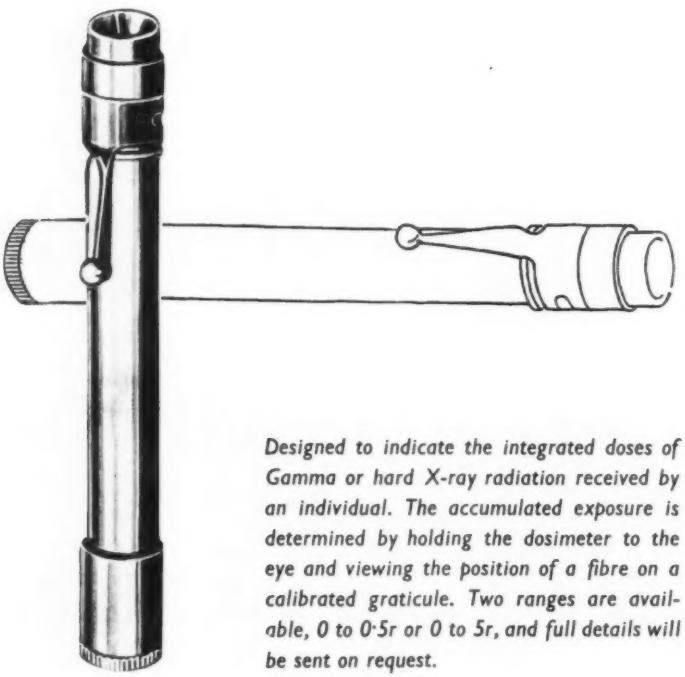

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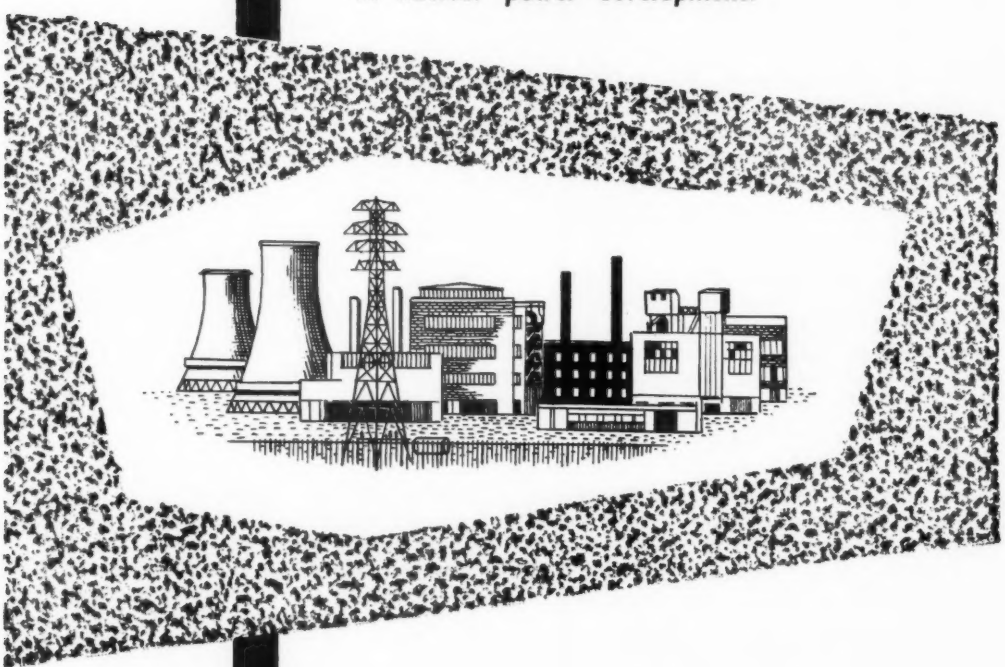

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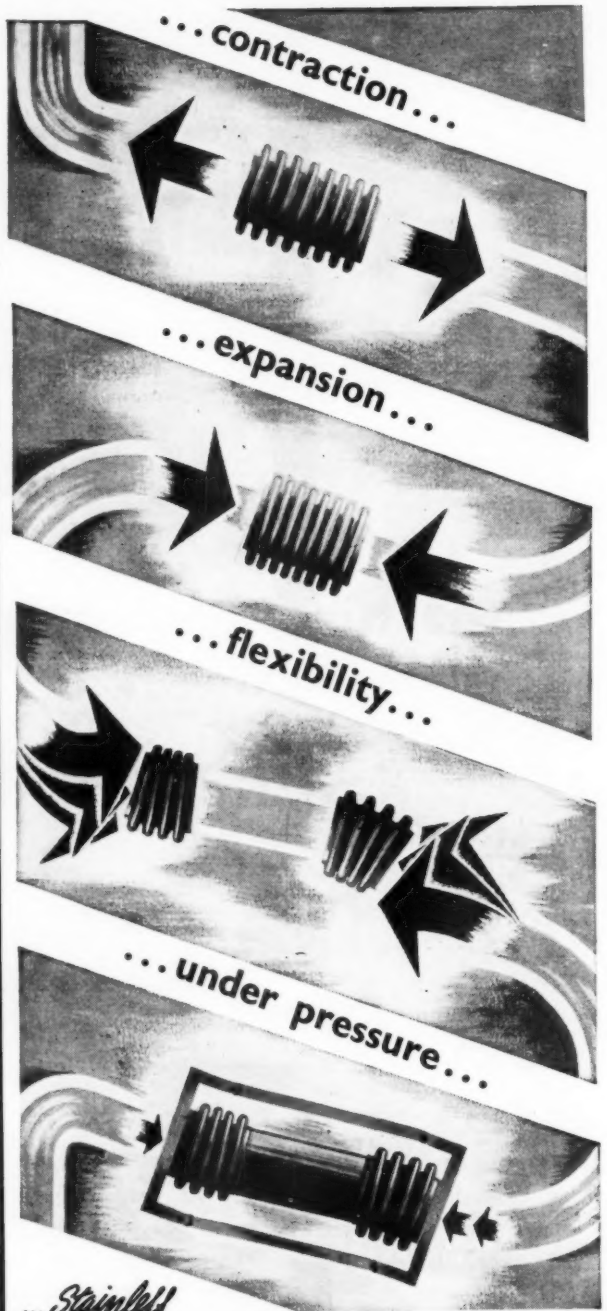

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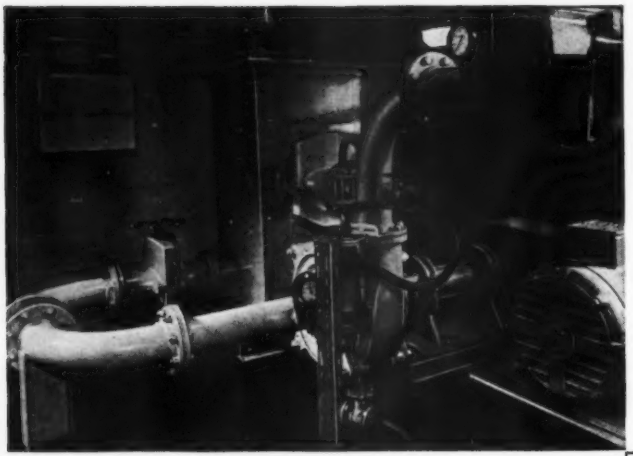

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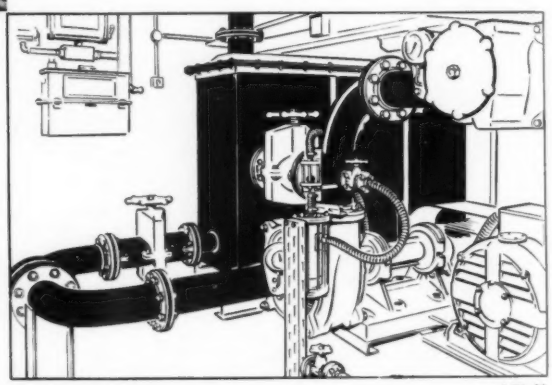

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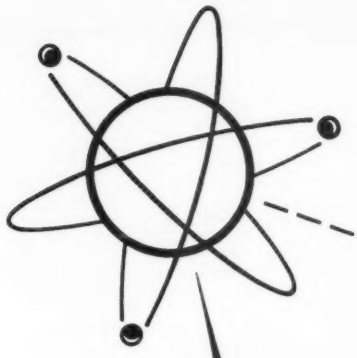

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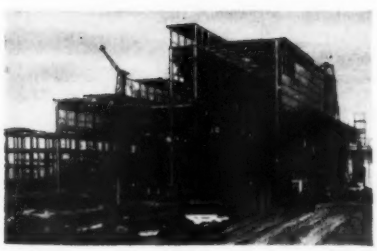

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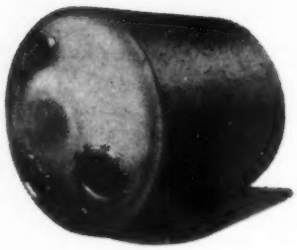

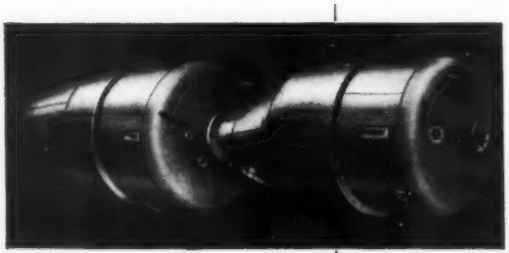

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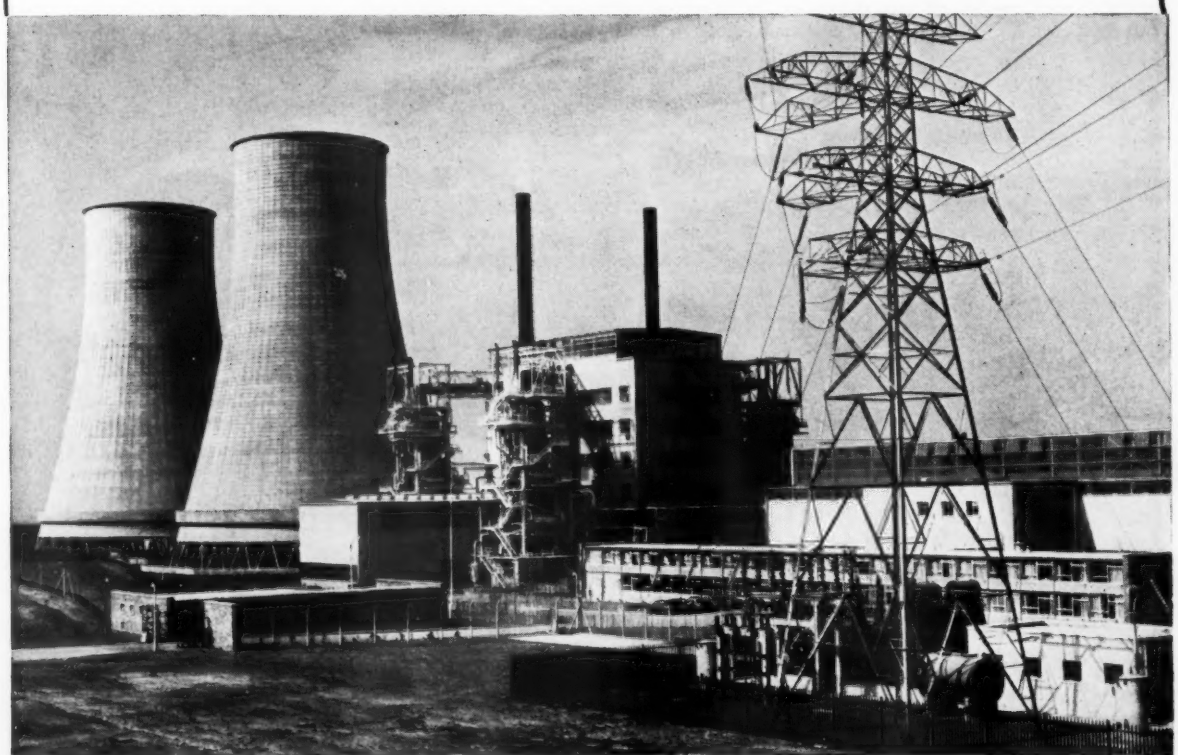

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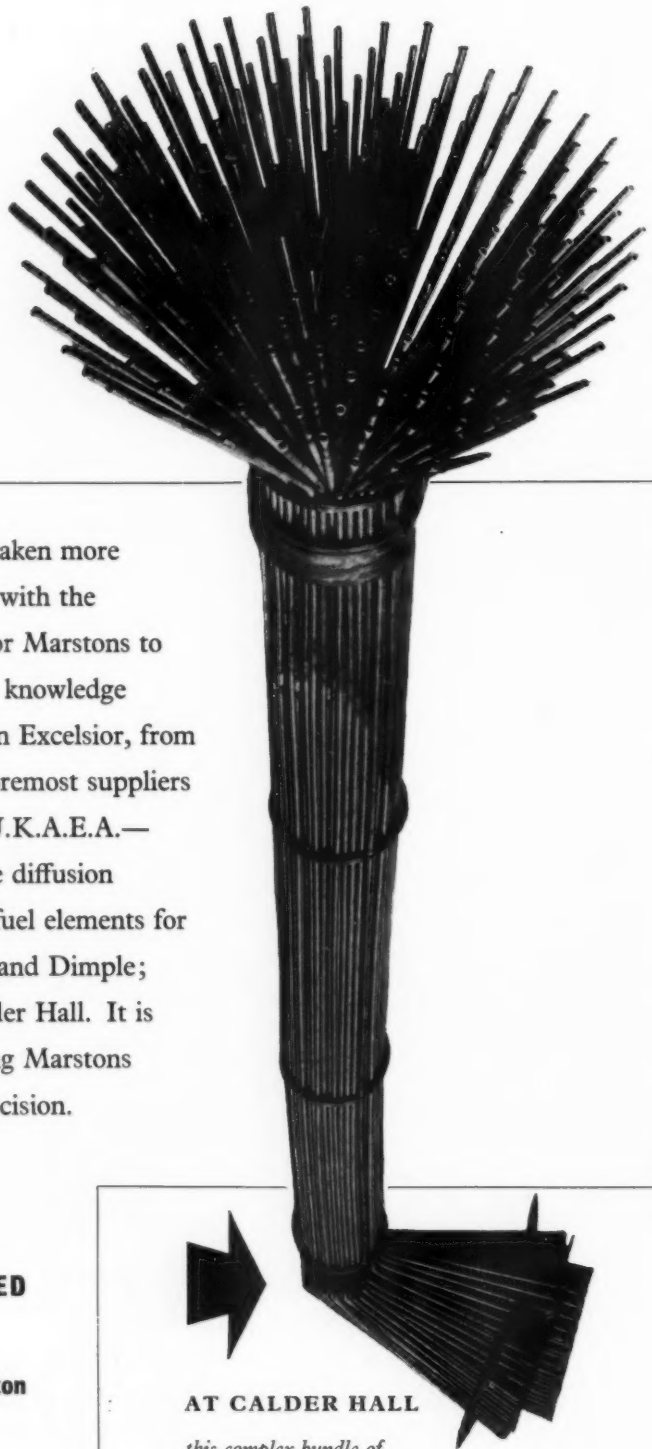

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MAR. 193

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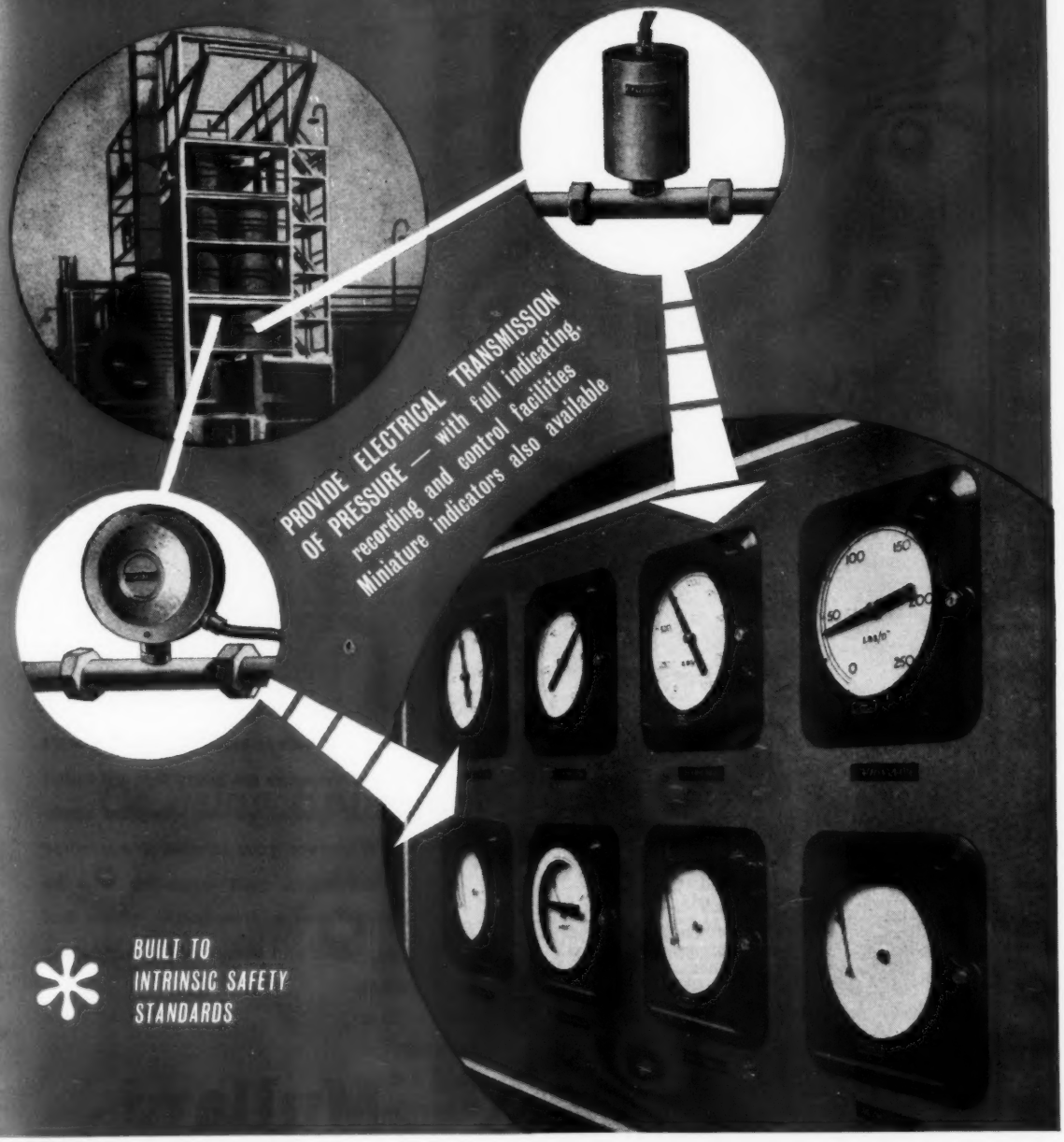
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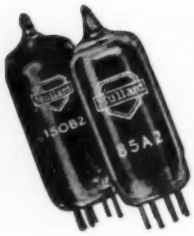

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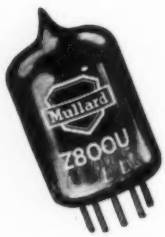

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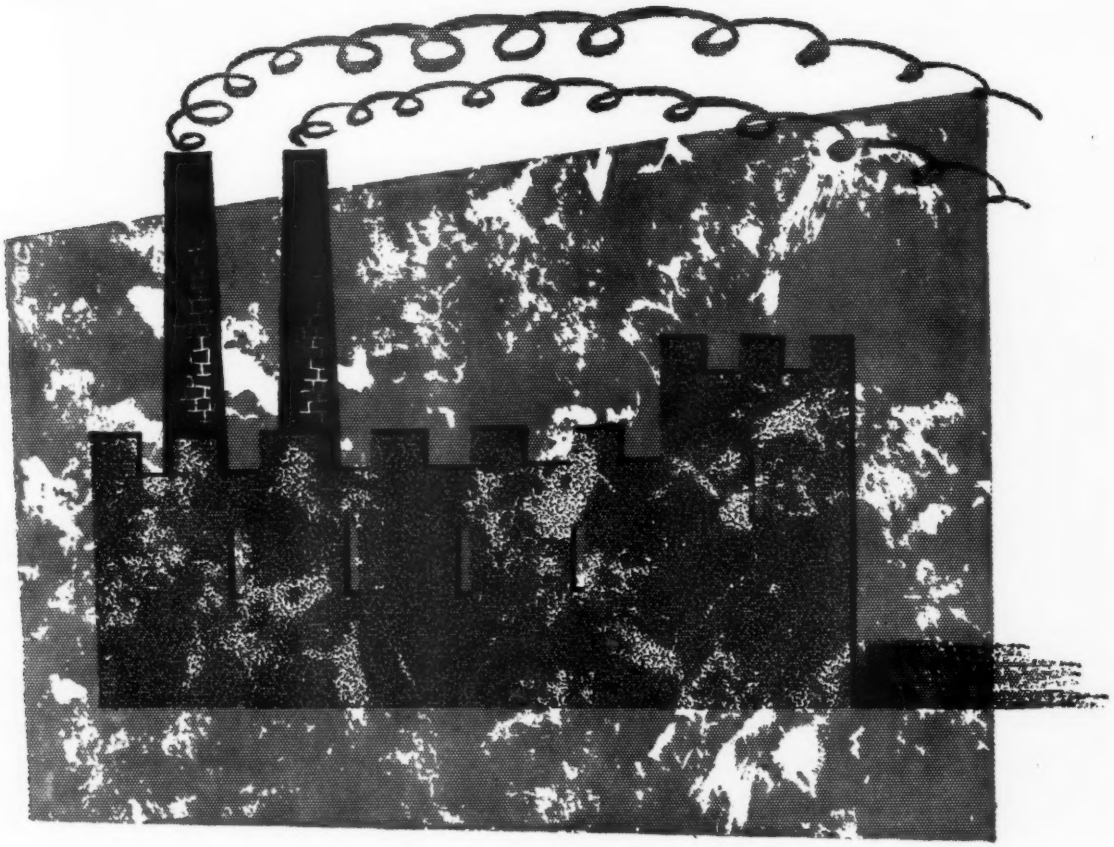

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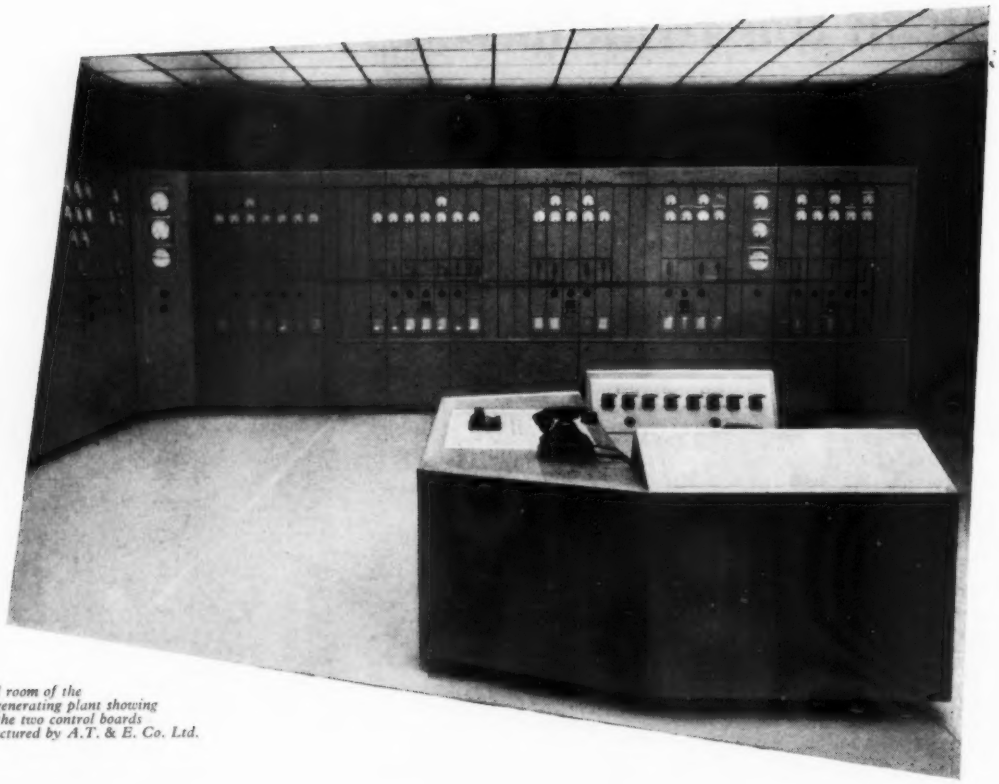

Control room of the power generating plant showing one of the two control boards manufactured by A.T. & E. Co. Ltd.

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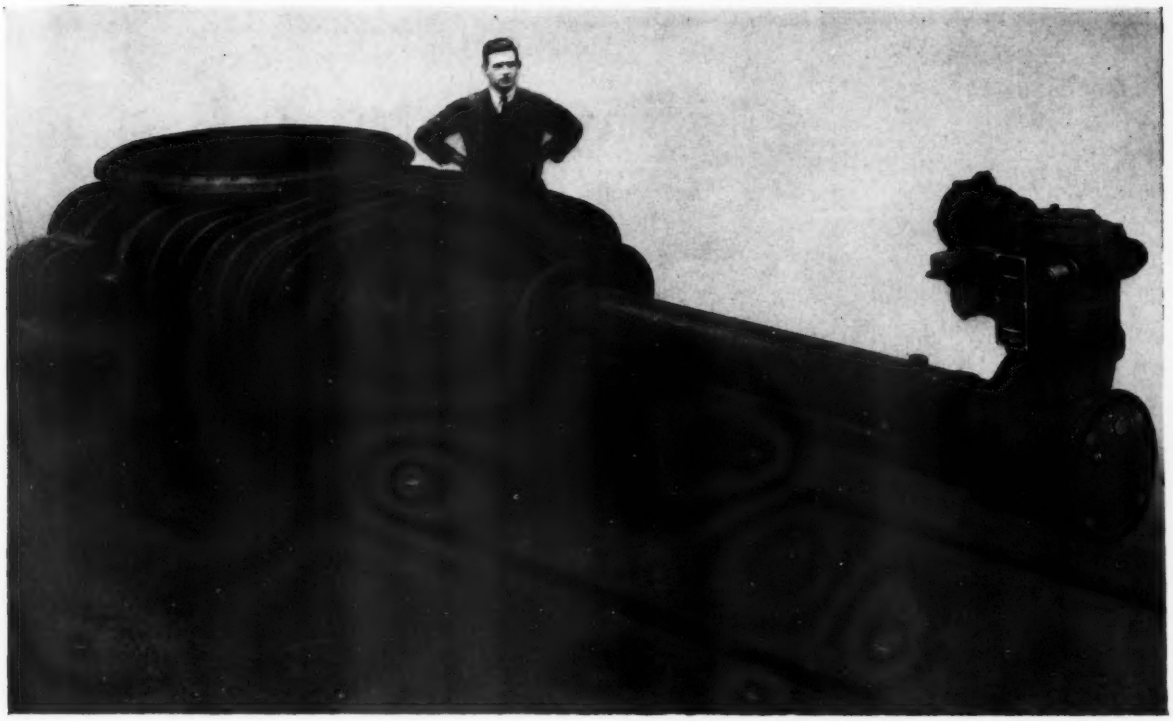

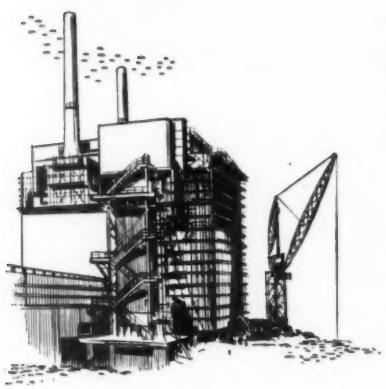

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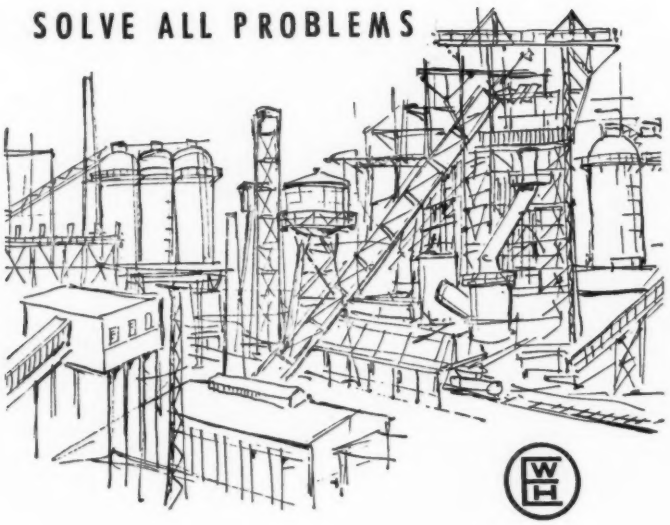

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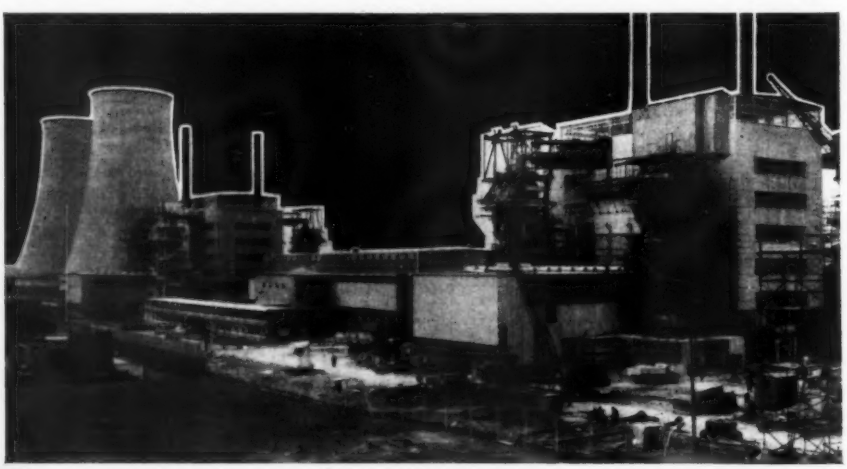

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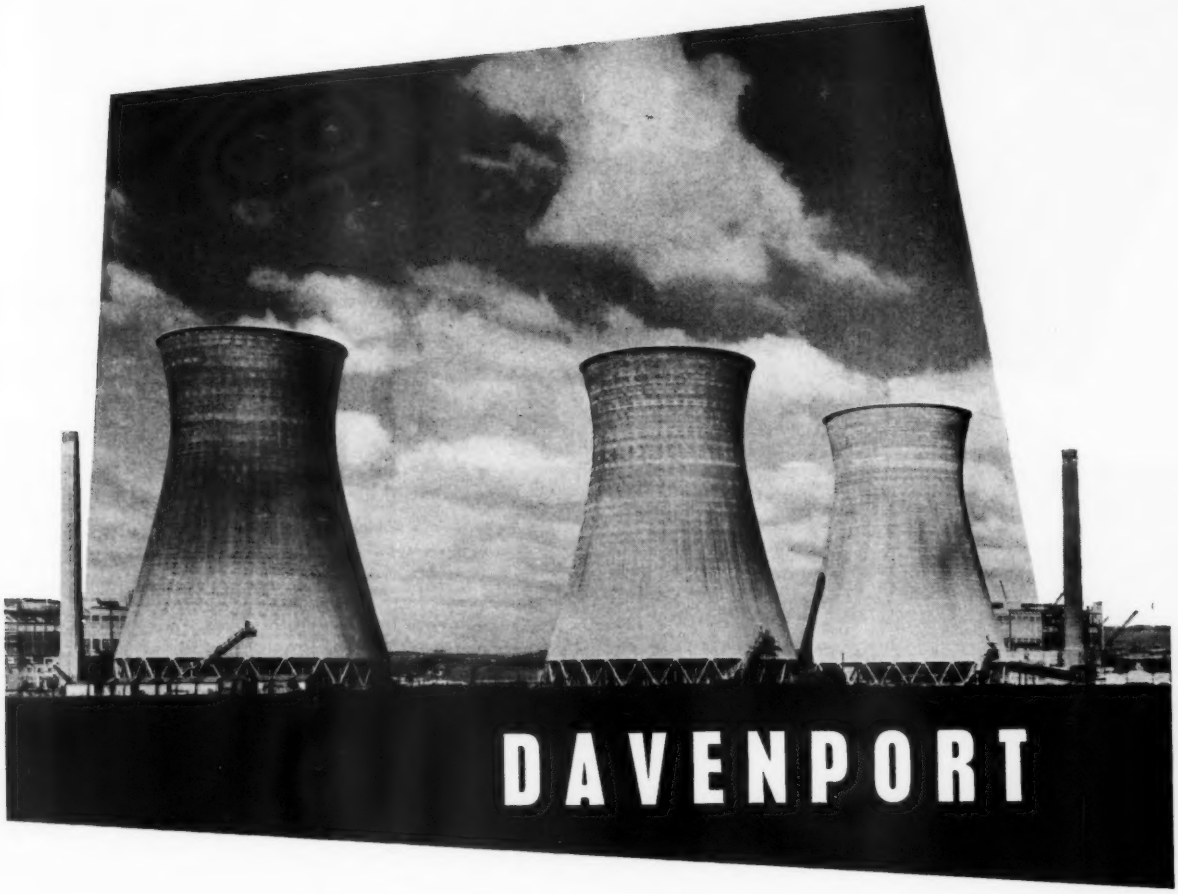

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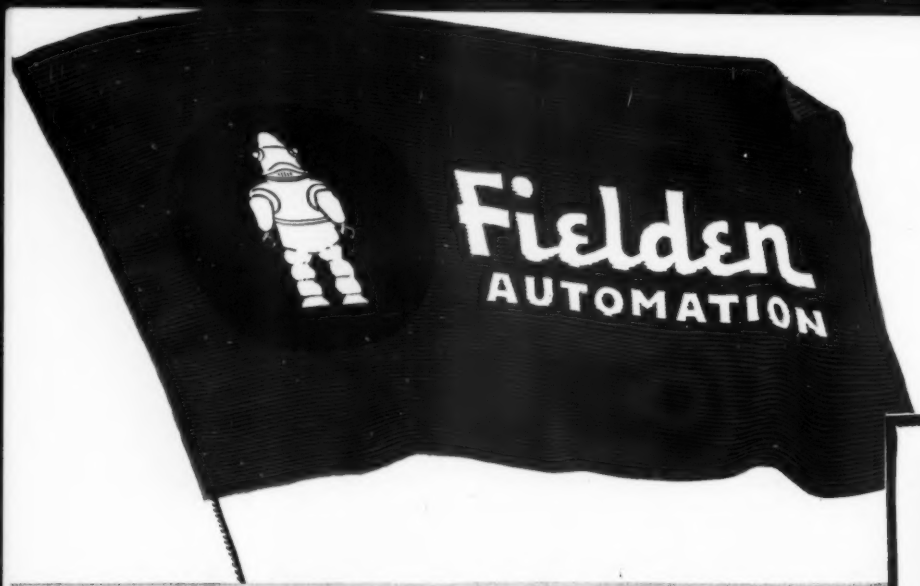
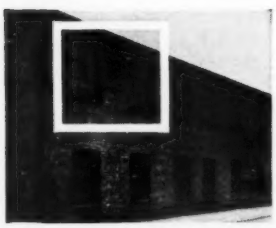
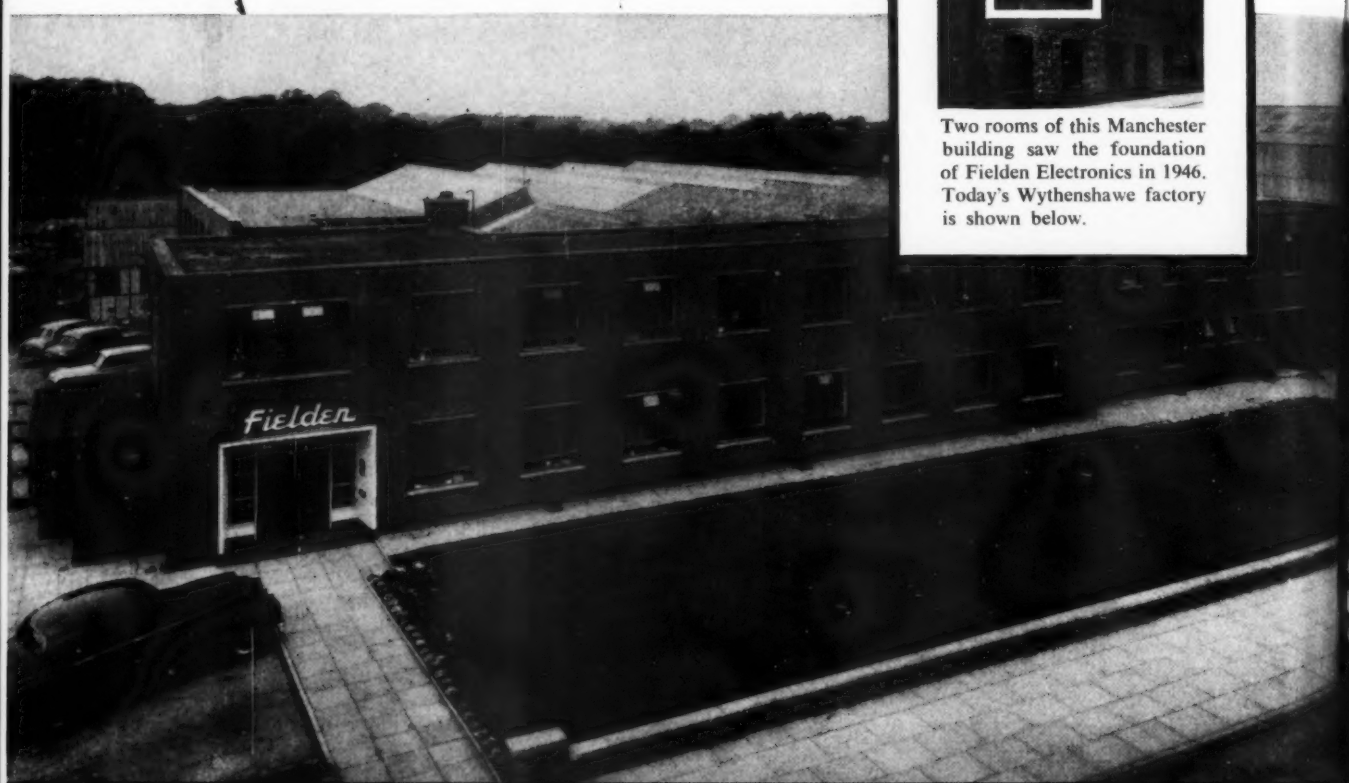




Two rooms of this Manchester building saw the foundation of Fielden Electronics in 1946. Today's Wythenshawe factory is shown below.



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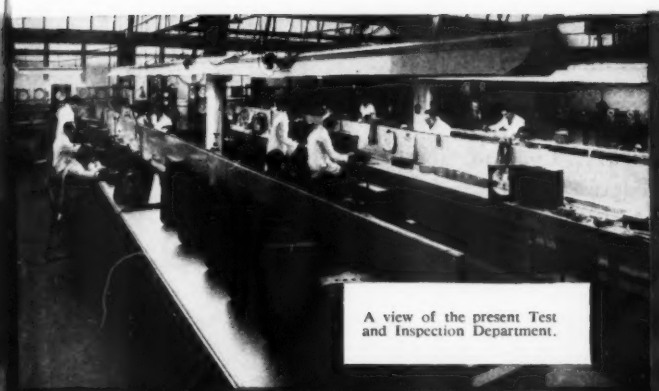
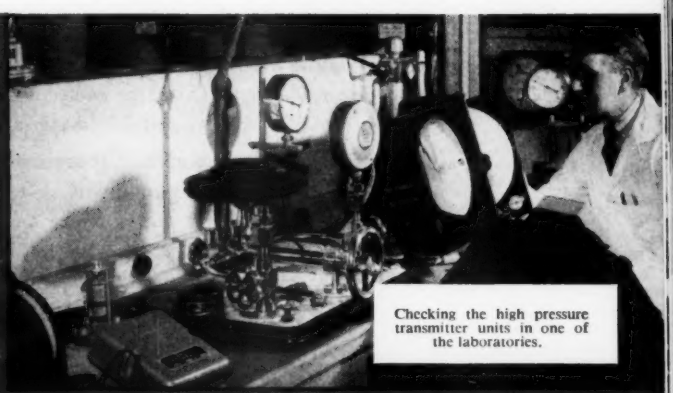


A view of the present Test and Inspection Department.



Checking the high pressure transmitter units in one of the laboratories.

Assembly line at the Wythenshawe factory, which employs over 300.

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The Calder Hall project involved a succession of new problems during construction, the testing nature of which was just another challenge successfully met by the skill of our engineers.

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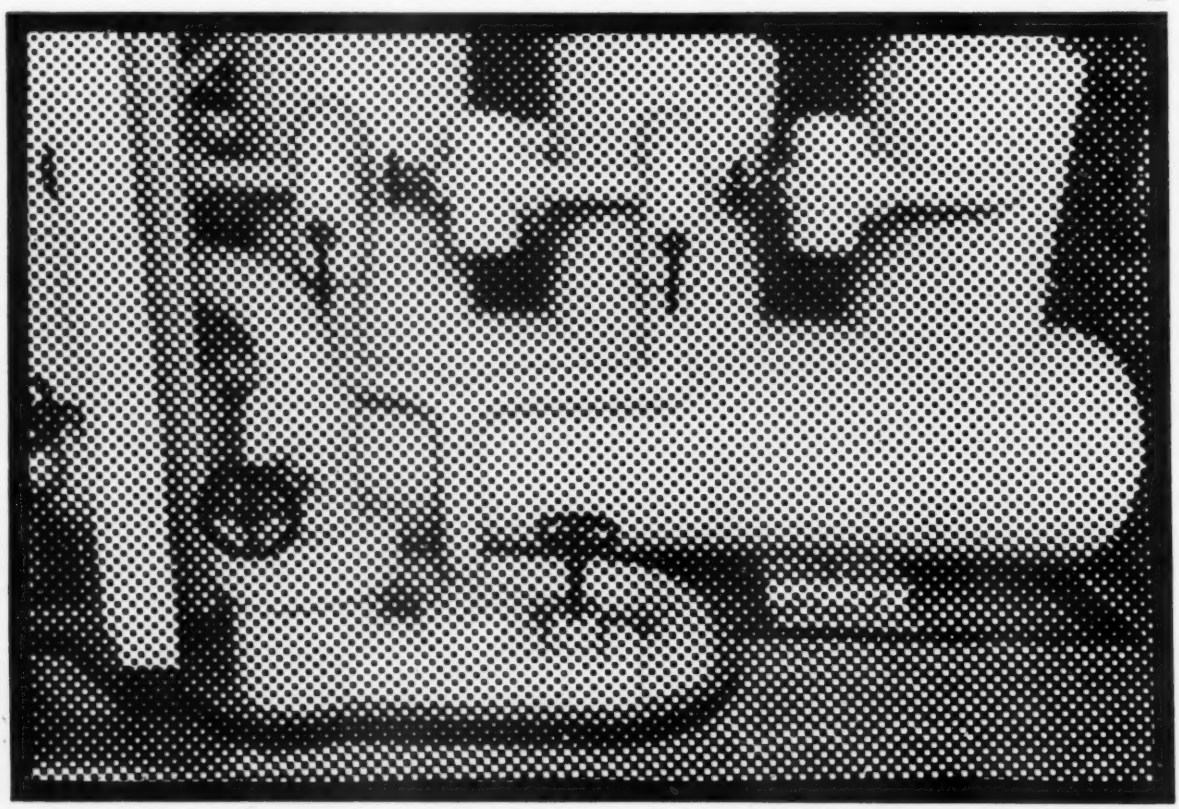

2nd of 3 **SPECIAL CALDER nos**

This issue of NUCLEAR POWER continues the description of Calder Hall power station which commenced last month. Details are given of the power plant, instrumentation, control system and other aspects of the station.

november 1956
volume I
number VII

Nuclear Power

The journal of British nuclear engineering

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AT CHAPELCROSS, *Annan, Dumfriesshire, where work is beginning on one of Britain's biggest atomic power stations, the* **Mitchell Construction Company** *are the main civil engineering contractors.*

AT CAPENHURST, *near Chester, where work at the Authority's diffusion plant is in progress, the same Company is building six cooling towers. Here, also,* **Mitchell Engineering Limited** *has been awarded a substantial contract for piping and plant installation.*

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Nuclear Power
NOVEMBER 1956 VOLUME I NUMBER VII

After Calder

ONE DAY LAST MONTH, marked by the simple ceremony at Calder Hall, Britain slipped into the lead in the race to obtain economic power from atomic fission. This is a cause for legitimate pride, but it must not blind us to realities. With limited design and production resources, we concentrated on the nuclear power reactor which posed the fewest problems. Calder Hall is the result of that policy, but it was built to the total exclusion of all other possible thermal reactors.

In nuclear energy British industry has two tasks. These are to some extent complementary, but in the main they are not, except in so far as they use the same basic theories and technologies. The first and most urgent is to provide for ourselves as quickly as possible a system of large base-load power stations capable of closing the coal gap. This is no mere prestige 'kilowatt race.' It is a race we must win in the next decade if we are to maintain, let alone increase, the standard of life of our people.

Our domestic programme is at present defined by the White Paper of February 1955. This modest plan is quite inadequate to bridge the gap between consumption and production of indigenous fossil fuel, but it must be remembered that when it was drafted Calder Hall was barely rising from its foundations and some prudence was desirable. Nevertheless the plan has served a useful purpose in clarifying ideas and it has also led to the formation of a nuclear energy industry in this country. That the plan is soon to be completely redrafted is no longer in doubt and this was indicated quite clearly by Mr Butler at the Calder Hall opening. Already the four industrial groupings competing for the initial 'electricity first' stations have made immense forward strides with the basic Calder design and there is little doubt that, as a type, it still has ahead of it some years of useful development. Clearly, a new plan to close the coal gap in, say, ten years must be based on this type of reactor. This does not mean that other types should be neglected. On the contrary, they must be pushed on with all possible speed. But we cannot wait for them: our need is for power now and this the Calder type can supply.

The second task for industry is one it has known for a century—and intimately for the last ten years. Many countries need nuclear power already and would be willing to buy suitable power reactors now if any fully-proven designs were available at an economic price. Unfortunately, although it is now proven, the Calder design is economic only in large sizes. It is in fact suitable only as a base load station for incorporation into existing grid networks. Such conditions exist in developed countries, but there are many lands in which this is not so.

What is needed for export is a small reactor with an electrical output of about 10-20 MW or even less which could be sent in pieces to almost any part of the world and which could supply current to a small, compact district. Such a plant would of course need enriched fuel and here is the crux of the problem. True, small natural uranium reactors could be built if heavy water were available (NPD is an example) but for us in Britain D_2O is even more difficult than enriched fuel. Clearly, this problem must be resolved sooner or later and we believe the way to do it is to give industry more rein than it has been allowed up till now. At the Calder opening, AEA chairman Sir Edwin Plowden implied that that would now in fact be done.

Nuclear energy is of course potentially a very dangerous business and even after a satisfactory international control is set up there will have to be some supervision of nuclear activities if only to protect the workers and the public. Nevertheless, recognising that certain restrictions must remain, some liberalisation could be done now. In particular, as long as the Government holds a complete fuel monopoly it is important that firms should be told exactly what fuel they can have, when they can have it and how much it will cost them. This would enable design work on advanced reactors to go ahead on a realistic basis. Naturally, Government inspection would be necessary at all stages but this need not be unduly restrictive, and there are good precedents for it in the aircraft industry.

TODAY the future unfolds at Calder Hall. When the seeds were sown four years ago, C. A. Parsons & Co. Ltd., who had been given the task of building special gas circulating plant necessary to harness atomic power, consulted Shell about lubrication. As a result of experimental work carried out at their Thornton Research Centre, Shell were able to provide a lubricant to satisfy the special conditions involved.

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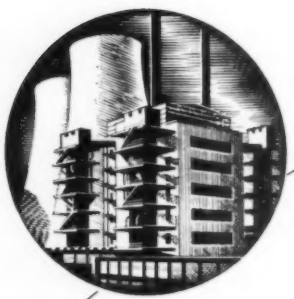

Atomic Power

FROM CALDER HALL

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The Queen 'makes history'

CALDER HALL OPENED

At 12.19 p.m. on Wednesday October 17th 1956, current from Calder Hall power station was switched into the 132kV grid of the Central Electricity Authority, and an enormous kWh meter mounted over the administration block began to rotate. Her Majesty The Queen had just finished speaking and had tripped a small lever on the dais. And so, on a brilliant but windy autumn day nuclear power arrived.

Earlier, her Majesty had had the working of the station explained to her with the aid of models and diagrams by R. V. Moore, GC, who was largely responsible for the design of the plant and she was then escorted over the station by the Works General Manager H. G. Davey. Her itinerary included the control deck of no 1 reactor, the fuel element preparation room, the burst cartridge detection gear room, the control room, the 'long' blower house and the turbine hall. During her tour, several presentations were made and rather than ballot for this honour, it was agreed that the men whose shift of duty happened to coincide with her Majesty's visit would be the ones to be presented. Afterwards, the Queen accompanied by Lord Privy Seal, Mr R. A. Butler, UKAEA Chairman Sir Edwin Plowden and other distinguished staff and guests made their way to a small dais on a lawn outside the station in full view of a grandstand full of guests and AEA staff. The general public were also admitted to a special enclosure.

All nuclear after 1965?

Speaking in place of Britain's minister responsible for atomic energy Lord President of the Council, The Marquess of Salisbury, who was indisposed, Mr R. A. Butler said that in years to come many power stations would be built in this country and overseas. But to Calder Hall would always belong the pride of having been the first station anywhere in the world to produce electricity from atomic energy on a full industrial scale. Possibly foreshadowing a revised British programme, Mr Butler said it might be that soon after 1965 every new power station would be nuclear. By 1975, he went on, the total output from atomic stations would certainly be more than—it might even be double—the output of all to-day's power stations together.

Calder Hall showed, continued Mr Butler, that electricity can be produced by burning uranium in nuclear reactors. We must remain among the leaders of the vast prosperity which can be won in the way we are striving to achieve to-day. This was only a beginning and we were already planning and working for the developments that lie ahead.

Birth of new industry

Following Mr Butler, Sir Edwin Plowden thanked The Queen for consenting to open the station and said that although one day they would look back on it with the feeling we now have for the first steam engine and the first aircraft, future achievements would not detract from this first great practical step forward. Sir Edwin referred to industry's part in the future and said that the AEA would remain a pioneering body. "It is industry," he went on, "that will be responsible for the developing and building of atomic power stations for the electricity authorities at home and abroad. To-day we see the birth of a new industry. If we follow up this first success with vigour and determination our country and the world will be assured of a source of power which will be inexhaustible for many generations to come."

Sir Edwin disclosed that in about a month's time the Authority were to open a Reactor Operations School at Calder Hall and that this would eventually take from Britain and abroad about a hundred students a year.

The AEA chairman concluded by asking Her Majesty to open the station.

The Queen's speech, next page
Pictures, page 300

Performance better than expected

NOT FULL OUT YET

On a Press visit to Calder Hall two days before the opening, it was noticed that the power level of No 1 reactor was then about 140MW thermal. Access to the turbine control room was not permitted, but it was understood that with two turboalternators on the bars, some 28MW were being delivered at that time. At a press conference, Mr H. G. Davey and Mr K. L. Stretch, Calder Works Manager, explained that when the Queen tripped the lever, some 10MW would be delivered to the Workington and Whitehaven areas. The exact amount would of course depend on the demand at the time. In answer to a question, Mr. Davey confirmed that the total ancillary power requirement per reactor at the full rated output would be between 8 and 10MW. This agrees well with the figure as forecast in NUCLEAR POWER (October p 258).

Spare reactivity

Reports that the reactor had been overheating were quite untrue, said Mr Davey, and the pile had in fact proved better in performance than theory had indicated. Spare reactivity was even more than was hoped for. It was true that carbon dioxide was being lost at the rate of about a ton a day. This had already been brought down from about four tons, but although the activity produced in the leakage gas was below tolerance level, steps were to be taken to reduce leakage even further. It should also be noted that the daily throughput of gas is over 250,000 tons a day. In the next few weeks, supply of electricity to the grid will not be very regular, for it is planned to close down the reactor for minor adjustments. When these are done, it will be gradually worked up to its full output of about 220MW thermal. Reactor 2 is practically ready for loading and criticality trials are expected to commence in December.

In answer to a question, Mr R. V. Moore said that the turbines were at present bladed to deliver 21MW at the maximum efficiency point. Blading modifications, which they might do during a routine stripdown, could raise the figure to 23MW.

The colour plate overleaf shows how fresh fuel elements are delivered to the Calder Hall reactors in steel boxes, each containing three cartridges. The total amount on this trolley will release heat equivalent to 3,750 tons of coal. Behind, no 2 reactor is nearly complete

TODAY, as power from Calder Hall begins to flow into the national grid, all of us here know that we are present at the making of history.

For many years now we have been aware that atomic scientists, by a series of brilliant discoveries, have brought us to the threshold of a new age. We have also known that on that threshold mankind has reached a point of crisis. Today we are, in a sense, seeing a solution of that crisis as this new power, which has proved itself to be such a terrifying weapon of destruction, is harnessed for the first time for the common good of our community.

In this turbulent century we have seen one technical revolution succeed another with astonishing speed. Within the span of a few generations our way of life has been transformed beyond anything our forefathers could have imagined. The age of steam was succeeded by an age of such startling achievement that we, who are close to it, can hardly realize that so short a period encompassed the invention of the motor car, the wireless set, the aeroplane and much else besides, which we now take for granted. So quickly have we learnt to accept the pace of modern development that we have been in danger of losing our sense of wonder.

That sense has been dramatically restored by the advent of the atomic age. We have been made vividly aware that the physical world, in which the great adventure of human life is lived, is of a complexity which must inspire in us a sense of awe. More than that ; in the atom, man has discovered vast powers and ways to control them, and their tremendous possibilities for good or evil must fill us with a sense of humility. As new fields open before us, we become conscious that a grave responsibility is placed upon all of us to see that man adds as much to his stature by the application of this new power as he has by its discovery.

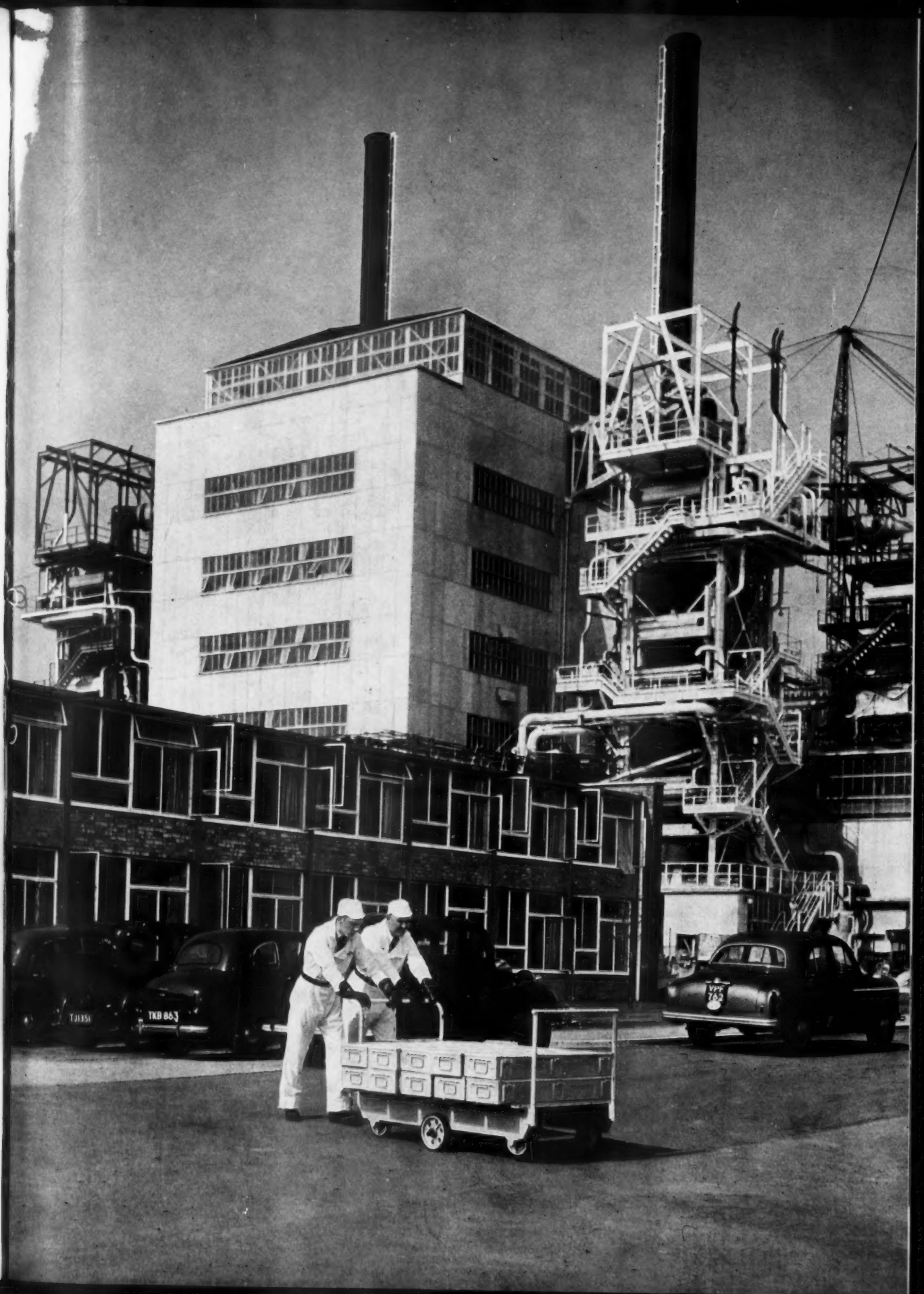
Future generations will judge us, above all else, by the way in which we use these limitless opportunities which Providence has given us and to which we have unlocked the door. They offer us, as we have heard today, a vital and timely addition to the industrial resources of our nation and to our material welfare. But above all we have something new to offer to the peoples of the undeveloped and less fortunate areas of the world, who will continue to look to us for assistance and example as they have done in the past.

That, to me, is the real importance of today's ceremony. For centuries past visionary ideals and practical methods which have gone from our shores have opened up new ways of thought and modes of life for people in all parts of the world. It may well prove to have been among the greatest of our contributions to human welfare that we led the way in demonstrating the peaceful uses of this new source of power.

I congratulate all those who have shared in this fine project—both those who conceived and planned the industrial application of atomic energy in this way, and those who have worked to see their plans fulfilled. I hope this occasion will be an inspiration and encouragement to all who will continue this exciting enterprise, here and elsewhere.

It is with pride that I now open Calder Hall, Britain's first atomic power station.

H.M. Queen Elizabeth II October 17th, 1956



Calder Hall. The No. 1 reactor control room, showing the control desk and KENT instrumentation (courtesy UK Atomic Energy Authority)

With the opening by H.M. The Queen of the first large-scale nuclear power station on earth at Calder Hall, Britain proudly demonstrates an ascendancy in a new world industry.

KENT takes equal pride in having been intimately associated with every major post-war nuclear development. From the earliest Harwell experiments to the latest power stations at Calder Hall and Chapelcross, the design, supply and installation of measuring instruments and control panels have been largely entrusted to KENT.

Instruments supplied include thousands of KENT Multelec recorders for the measurement and control of radioactivity, reactor power level, pH, conductivity, B.t.u. and temperature; KENT flow recorders and draught gauges for the measurement of air, steam and gas; and hundreds of complete control panels.

The valuable experience thus gained, added to substantial participation by KENT in closely allied industries such as steam generation, places the Company in the strongest possible position to contract for the engineering and building of instrumentation for all nuclear-power projects.

Whatever the future may hold for this great industry, KENT is destined—and qualified—to play a leading part in it. As and when entirely new types of instruments become necessary, KENT, with its unrivalled resources of knowledge and experience, is equipped to produce them.

KENT

MASTERS OF INSTRUMENTATION

Write for Publication, "Control of Variables in World Industry," to Atomic Energy Contracts Dept., Luton

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MEN OF CALDER

Many thousands of men, both from the United Kingdom Atomic Energy Authority and from British industry, contributed in amounts large and small to the building of Calder Hall power station. It would be wrong to single out any one, for throughout they worked as a team. Nevertheless, NUCLEAR POWER is proud to record the contributions of some of the leading scientists and engineers of the Authority from the Industrial and Research Group.

Atomic Energy Research Establishment Harwell

SIR JOHN COCKCROFT, KCB, CBE, FRS, Director, Atomic Energy Research Establishment

DR J. V. DUNWORTH, CBE, Head of Reactor Division

DR H. M. FINNISTON, Chief Metallurgist. Responsible for basic work on fuel element design

DR P. FORTESCUE, formerly in charge of the Engineering Laboratory. Responsible for basic work on heat transfer problems in reactor design

MR B. L. GOODLET, OBE, formerly Deputy Chief Engineer. Responsible for supervision of feasibility study

MR C. A. RENNIE, formerly Deputy Head of Reactor Physics Division. Responsible for theoretical physics advice on reactor design

DR R. SPENCE, CB, Chief Chemist. Responsible for co-ordination of basic chemical studies involved in reactor design

DR D. TAYLOR, Head of Electronics Division. Responsible for development and production of nuclear instruments for reactor control

MR H. TONGUE, CBE, formerly Chief Engineer

Industrial Group Risley

SIR CHRISTOPHER HINTON, FRS, Managing Director, Industrial Group. Overall responsibility for design, construction and operation

MR W. L. OWEN, CBE, Director of Engineering. Responsible for the overall design and construction under Sir Christopher Hinton

MR P. T. FLETCHER, Deputy Director, Engineering. Mr Owen's Deputy. He has, for some time, acted as Chairman of the Progress Meetings held monthly to review construction

MR J. B. W. CUNNINGHAM, Deputy Director, Reactors. Was, for a considerable period, in charge of the design office which designed the Calder Hall plant

MR R. V. MOORE, GC, Assistant Director, Civil Reactors. Was concerned at Harwell with the early studies on power producing reactors. During a long period of illness of Mr Cunningham, he took charge of the project.

MR T. L. VINEY, Deputy Director, Works and Buildings. Responsible for the architectural aspects of the design and recently for all construction work

MR E. L. ASHLEY, Chief Engineer, Construction. Since 1954 he has had the responsibility for liaison between design and construction staff

MR J. D. GLANVILLE, OBE, Chief Engineer, Inspection and Progress. Responsible for the inspection of equipment and ensuring that it was delivered to site in conformity with the programme

MR K. B. ROSS, Director of Operations. Has overall responsibility for all factories

MR D. W. COLE, Deputy Director of Operations, Engineering. Is responsible under Mr Ross particularly for the engineering side of the factories

MR H. G. DAVEY, Works General Manager, Northern Area, has charge of the factories at Windscale, Calder Hall and Chapelcross

MR K. L. STRETCH, Works Manager, Calder Hall. Is responsible to Mr Davey for the commissioning and operation of the plant.

MR L. ROTHERHAM, Director of Research and Development. Is responsible for all research and development work carried out in the Industrial Group

MR L. GRAINGER, Chief Metallurgist. Was until recently in charge of the laboratory in which the development work on fuel elements for Calder Hall was carried out

CALDER HALL

Two-pressure steam and dump condensers give efficiency plus flexibility

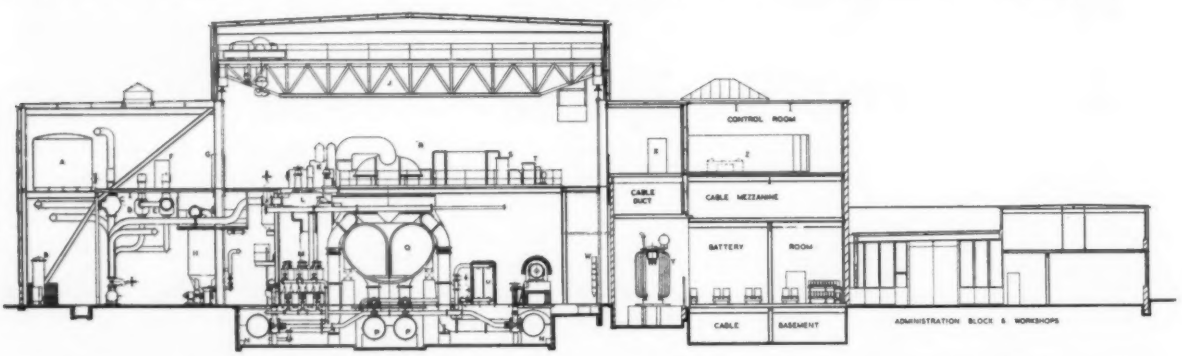
THE POWER PLANT

THE TURBINE HALL is a rectangular steel-framed building 242 ft long by 119 ft 6 in. wide, clad with asbestos cement panels and patent glazing. It contains four turboalternator sets by C. A. Parsons & Co Ltd, Newcastle upon Tyne. The sets are arranged on mass concrete foundations in side by side formation on the first floor level, the condensers etc. being at ground level. The turbines and alternators are on separate blocks with the condensers between. The volumes are 175 and 125 cu yd respectively and the blocks were each poured in one day. Telephones were used between the men working vibrators within the shuttering and those feeding concrete through flexible piping to ensure complete coordination. The hall is spanned by a 60-ton travelling gantry crane with a 12-ton auxiliary hook, by the Wharton Crane and Hoist Co Ltd. The lighting installation in the turbine hall, and in fact throughout the station, was carried out by N. G. Bailey & Co Ltd.

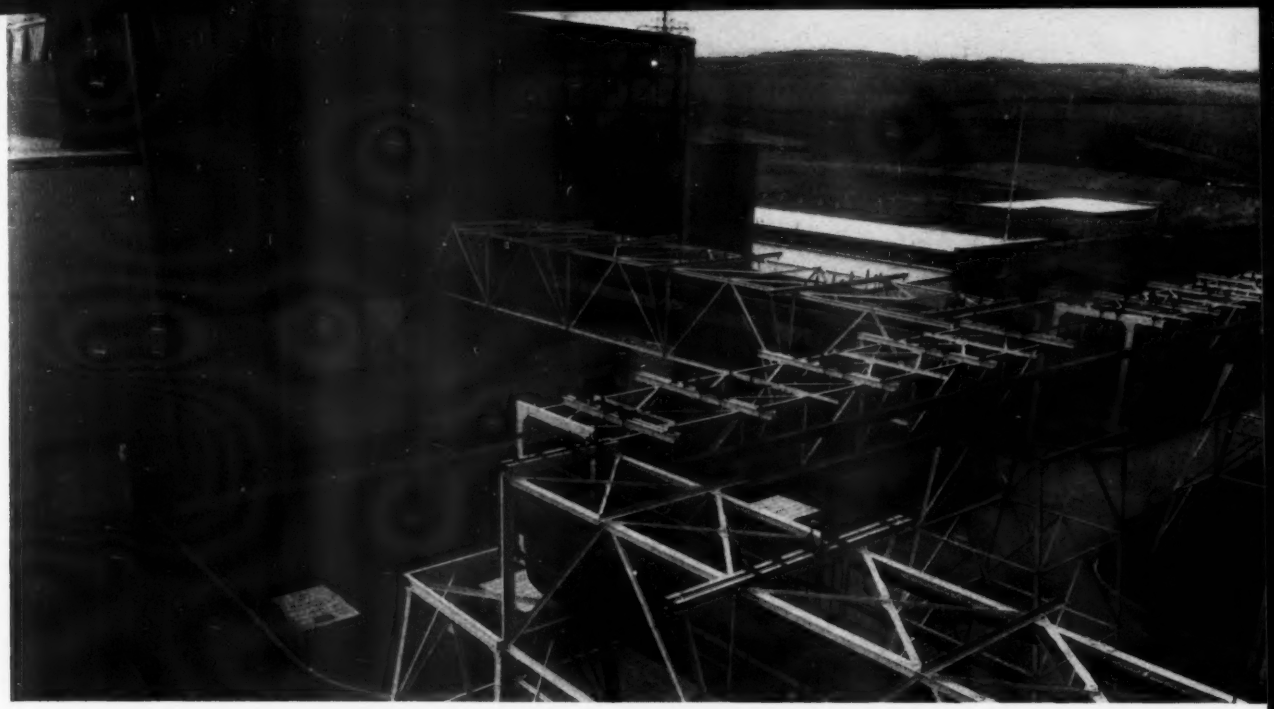
The maximum efficiency of the turbines is obtained at an MCR of 21MW, but minor blading modifications will permit this to be increased to 23MW.

The turbines are two-cylinder tandem machines comprising a single-flow high-pressure turbine and a double-flow low-pressure one, the two sections being solid coupled. There are two steam chests on opposite sides of the h.p. cylinder each with an emergency stop-valve and governor-valve. The h.p. and l.p. steam is received at both ends of the hall from the two reactors and is fully cross-connected by four h.p. and four l.p. manifolds on the ground floor level ; one of each being located opposite each set. The steam mains are all $\frac{3}{8}$in. thick, 16in. diameter carbon steel, fabricated and installed by Aiton and Co Ltd. Bellows expansion joints are extensively used.

The h.p. steam is supplied to the turbine at 200 lb/sq in. abs and 590°F. The first 15 stages, which have shrouded blades, carry h.p. steam only (77 per cent of the total mass flow of 257,300 lb/h). This expansion leaves the steam in approximately the same condition as the l.p. supply (53 lb/sq in, 340°F) which enters at this point from the l.p. chest. Seven further stages of unshrouded blades now carry the whole 100 per cent to the end of the h.p. cylinder and the steam is then taken to the l.p. cylinder through twin transfer pipes, lagged and cased in hammered aluminium. The low pressure turbine is a double flow machine which provides a liberal exhaust area with a relatively low blade tip speed. Throughout, the blading is of the all-reaction type: it is in stainless iron, the last two l.p. rings having stellited edges. The turbine and alternator shafts are forgings by Thos. Firth and John Brown Ltd, of Sheffield, who also supplied the runaway stop valves, governor valves and other parts.



Cross section of turbine hall shows: A surge and storage tanks; B demineralisation plant; C l.p. steam control valve; D l.p. steam dump valve; E h.p. steam dump valve; F primary desuperheater panel; G turbine gauge board; H main deaerator vessel; J 60-ton crane. 12-ton auxiliary hook; K oil purifier; L steam chest; M oil coolers; N cooling water outlet mains; P cooling water inlet mains; Q condenser; R 23MW turboalternator; S main field suppression switch; T field regulator; U alternator air coolers; V alternator air fan motor; W 415V distribution board. Turbine auxiliaries; X 415V and 3.3kV switchgear; Y 30MVA reactor. Station auxiliaries; Z control board and desk



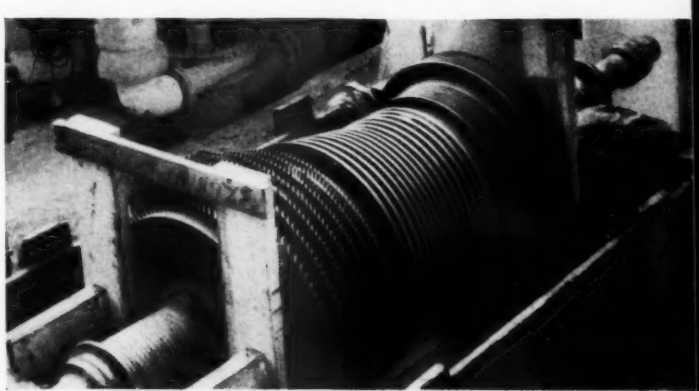
From reactor no 1, h.p. and l.p. steam mains are carried on a pipe bridge to the turbine hall. The two black vertical pipes to the left on the hall are from the relief valves through which steam can be discharged in an emergency

Early design studies of the steam cycle proposed a different arrangement of heat exchangers to that finally adopted. It was then intended to have the l.p. superheater at the top of the tower and to superheat the l.p. steam to the full h.p. superheat temperature. The l.p. steam entering the turbine would then have had the effect of reheating the partially expanded h.p. steam and so improving the exhaust conditions. However, it was considered undesirable to introduce high temperature steam at an intermediate stage in the turbine owing to the risk of thermal shock and so the present arrangement was adopted in which the l.p. steam enters with conditions the same as the h.p. steam at that stage. The final dryness fraction is about 88.3 per cent (NP. Oct. p 257).

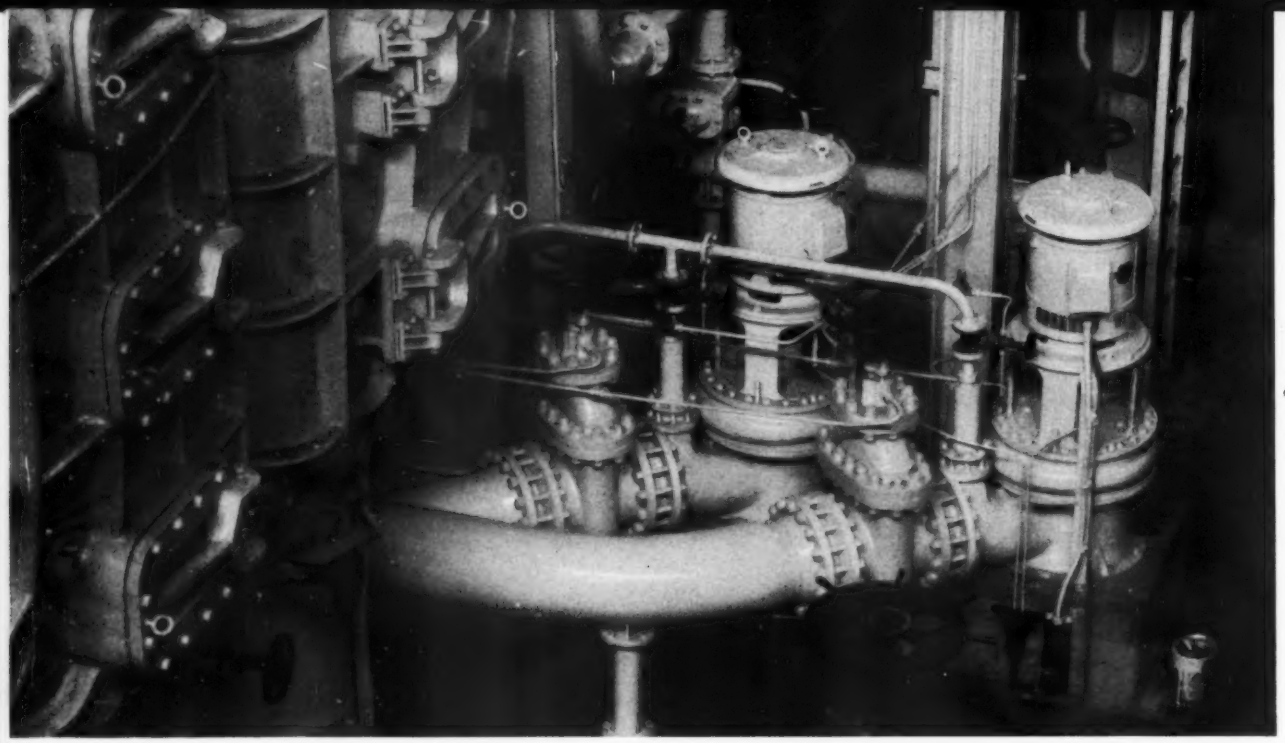
The h.p. and l.p. governor valves, emergency stop valves, and the steam pressure regulator are operated by power oil supplied by a gear-type oil pump mounted on a cross-shaft driven by worm gearing from the steam end of the h.p. turbine shaft. A lubricating oil pump supplying oil to the oil coolers and bearings is mounted on the same shaft, and the oil is continuously treated in Hopkinson centrifugal purifiers.

The condensers are of normal Parsons design with two halves and three passes. The total surface is 32,500 sq ft and the 1 in. diameter holes are expanded into the tube plate at one end and sealed off with metallic packing and ferrules at the other. The design vacuum is 28.25 in. on a 30 in. barometer.

Since the heat output from the reactors cannot be controlled quickly—indeed, heat continues to be evolved long after the shut-down rods are in—means have to be provided to absorb the output when the sets are out or on reduced load. Under these conditions, the steam from the heat exchangers is passed to a pair of dump condensers—one at each end of the turbine hall. Each of these can carry the whole steam output from one reactor and are twin-shell units. Before passing into the dump condensers, the steam is passed through primary desuperheaters using thermostatically controlled nozzles which lower the temperature to about 300°F. The desuperheater control cubicles on the turbine floor contain both mechanically-operated 8-ways spray control valves and, for fine control, electrically-operated 2-way spray control valves, supplied by Hopkinsons Ltd. Secondary desuperheaters located in the top chamber of the condensers reduce the steam temperature to saturation. Condensate from the dump condenser is



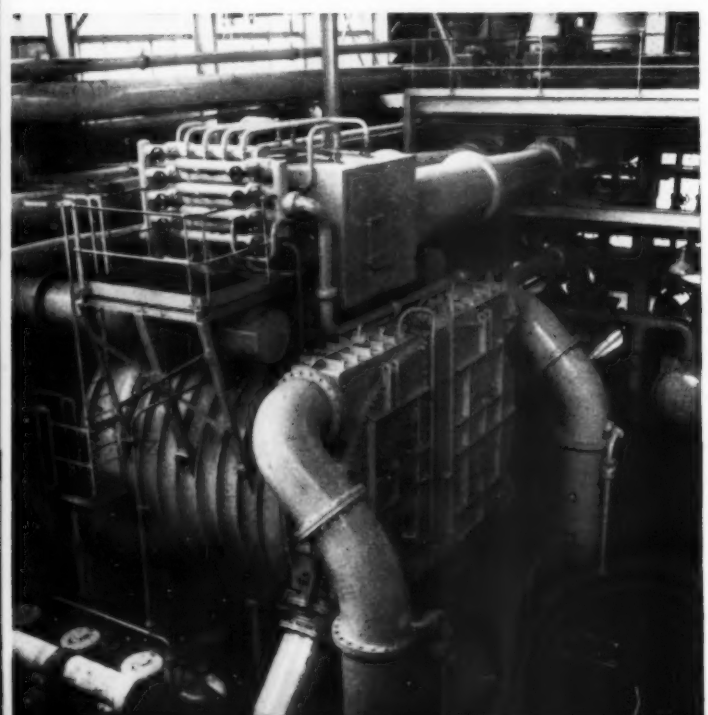
When the high pressure steam has expanded to 53 lb/sq in. at the 15th stage in the h.p. rotor, it is joined by low pressure steam for a further seven stages. Taken during turbine erection this view shows the change of blading



Twin vertical centrifugal pumps extract condensate from one of the four turbine condensers

first passed through a dump cooler before joining the boiler feed circuit.

When steam dumping is being done normally, the dump condenser circulating water pumps and extraction pumps are running and control is obtained from oil-operated valves connected to the pressure regulators and governors. If the output is all being used and through some fault condition it becomes necessary to dump steam, Hopkinson dead-weight relief valve set at 10 lb/in, located just downstream of the primary desuperheaters discharge the output to the atmosphere through pipes going vertically through the turbine hall roof.



On leaving the condenser extraction pumps, the condensate is passed to an air-ejector condenser with a line to the top of the main condenser through which most of the air is removed. The condensate then passes to a deaerator storage tank and through a Hick Hargreaves deaerator the vapour from which is condensed in a vapour condenser and the air removed by a steam-actuated air-ejector. An extraction pump clears the deaerator and passes the air-free feed water through a feed-cooler, in which the temperature is finally adjusted, to a battery of eight Mather and Platt multi-stage d.c. boiler feed pumps. Separate rectangular steel surge tanks are installed for each turbine set. These are located on the turbine floor and communicate with the deaerator storage tanks.

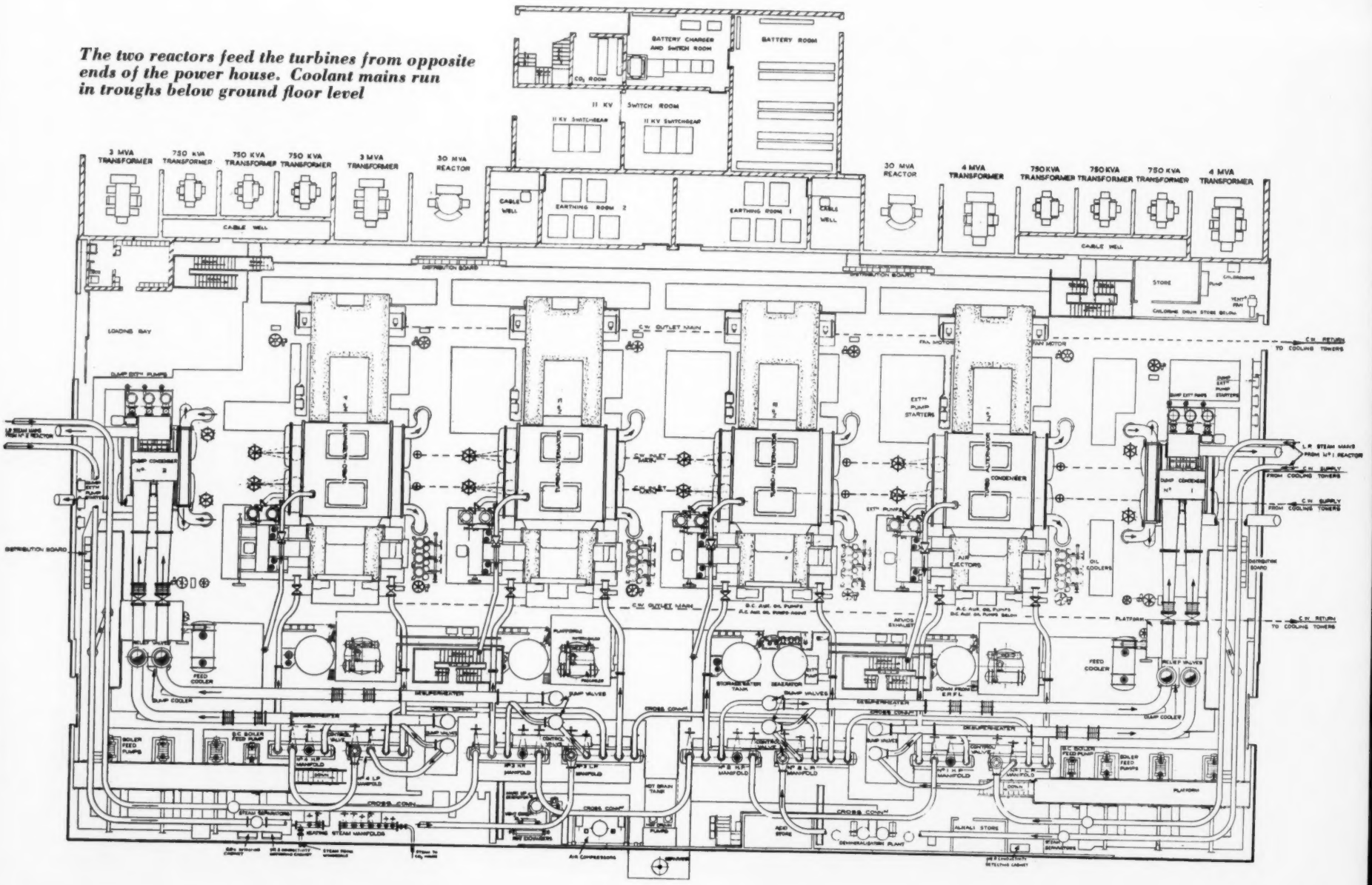
Before entering the mixed economizer section of the heat exchangers, the feed mains divide into separate h.p. and l.p. sections each of which incorporate a Weir automatic feed water regulator.

Forced circulation is maintained in the boilers, the flow being about four times the steam mass flow. There are separate circulation pumps for the h.p. and l.p. sections, the pumps being located in separate pumphouses, one under each boiler. The high-pressure circulation is by Hayward Tyler glandless pumps (NUCLEAR POWER October, p 259) and the low pressure by Mather & Platt pumps. For normal operation, one of each type is in use but in all cases they are duplicated by a standby unit.

Owing to the severe consequences of any scaling troubles in the heat exchanger elements a very high

Secondary desuperheating is provided to ensure that the steam is fully saturated before it enters the dump condenser. This is done by further sprays in a chamber before the condenser inlet

The two reactors feed the turbines from opposite ends of the power house. Coolant mains run in troughs below ground floor level

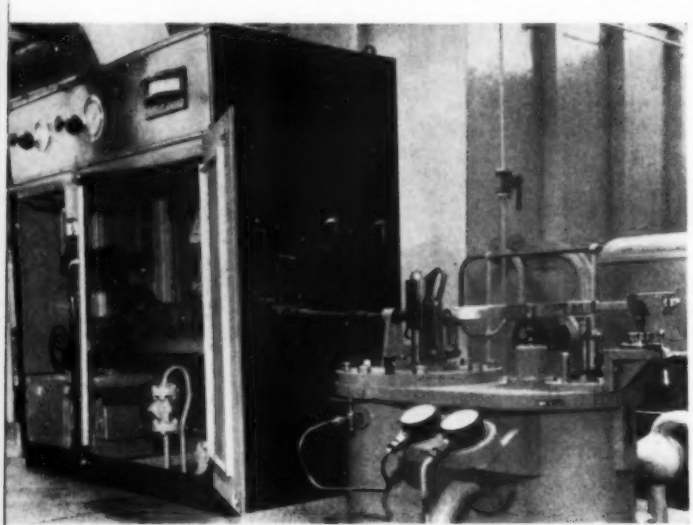


Steam is distributed to the turbines through a number of cross-connected steam manifolds (left). Across the aisle, one of the four deaerators and its storage tank remove air from the condensate

standard of treatment is needed for the feed water make-up. Raw water is obtained from Wastwater, a large lake about 8 miles away to the east. After passing through a Permutit ion-exchange demineriali-zation plant, the water is deaerated and then fed into the boiler feed circuit.

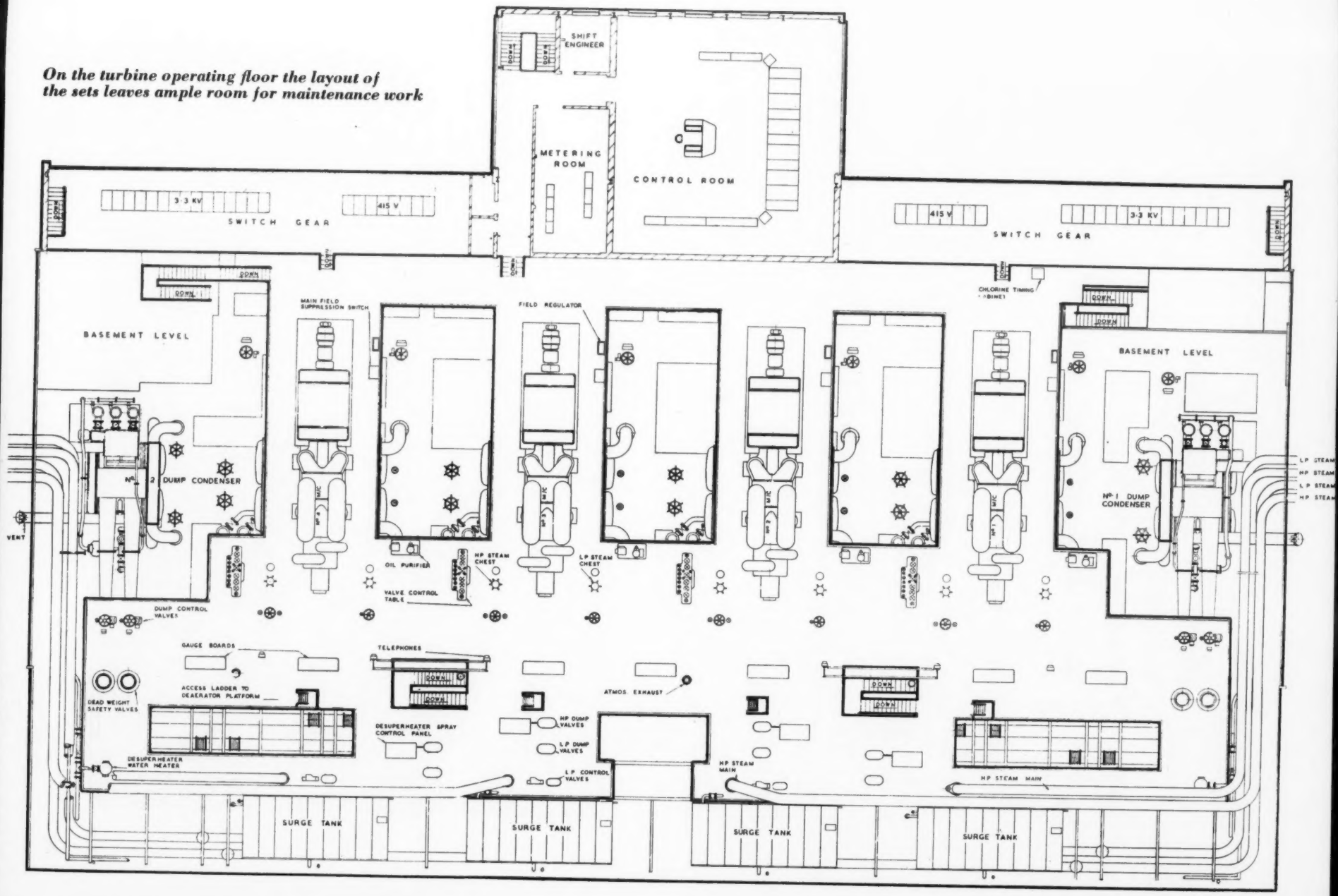
A closed circuit cooling water system is used for the condenser circulating water. The condenser inlet and outlet mains run in a trench below the ground floor level in the turbine hall. There are two natural-draught cooling towers of the hyperbolic reinforced concrete type situated on the station axis to the south of no 1 reactor building. Two basins are used in each tower, with half-basin capacities of 687,800 gallons. The two towers feed into a common suction basin at the pump house, with dam boards for partical shut down. Five 640 hp pumps are available for circulating the water, four normally being in use. The towers are 290 ft high above the sill, 200 ft diameter at the ring beam and 104 ft at the throat. Water is received at 85°F and dropped to about 70°F under design conditions, 47°F wet built, 52°F dry bulb (60 per cent humidity). The capacity of each tower is 3 million gallons an hour.

Construction was carried out in 3 ft lifts and a rate of a lift a day was reached and maintained. Work was carried out from an internal scaffolding of prefabricated steel and as it progressed upwards in the first tower, the upper sections were suspended from the steel to release the lower part for use in starting the second tower. The consultants, L. G. Mouchel & Partners Ltd were responsible for the design of the towers, construction being by Taylor Woodrow Ltd.

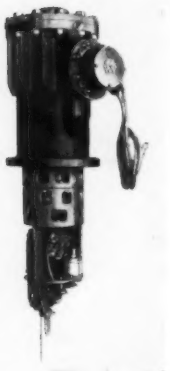


Before steam is dumped the superheat must be removed. This is done by spraying it with water as it passes on its way to the condenser, automatic temperature control being provided

On the turbine operating floor the layout of the sets leaves ample room for maintenance work



Rod drives operate completely inside pressure vessel: vertical layout provides gravity shut-down



CONTROL ROD ACTUATORS

THE CONTROL ROD SYSTEM was developed by Metropolitan-Vickers Electrical Co Ltd for the UKAEA over a period of several years, and provides failure-to-safety under all conditions, consistent with maximum reliability of operation

The Type GB27 actuating mechanisms, 60 of which were supplied for each of the two piles, combine the functions of control and shut-off. Vertical operation of the rods permits the use of gravity for shut-off. Controlled braking is used so that a high launching speed combined with slow touchdown is attained.

Each unit is contained in a steel casting and is designed to work within the gas circuit at 100 lb/sq in., the only connection with the outside being electrical leads, which are taken through glass-to-metal seals. Severe space limitations and virtual impossibility of maintenance were important factors in the design of the actuators.

The control rod assembly weighs 130 lb with an operational travel of 21 ft, and is suspended by a special low-cobalt flexible stainless steel cable edge-wound on a narrow drum between side cheeks spaced one cable diameter apart.

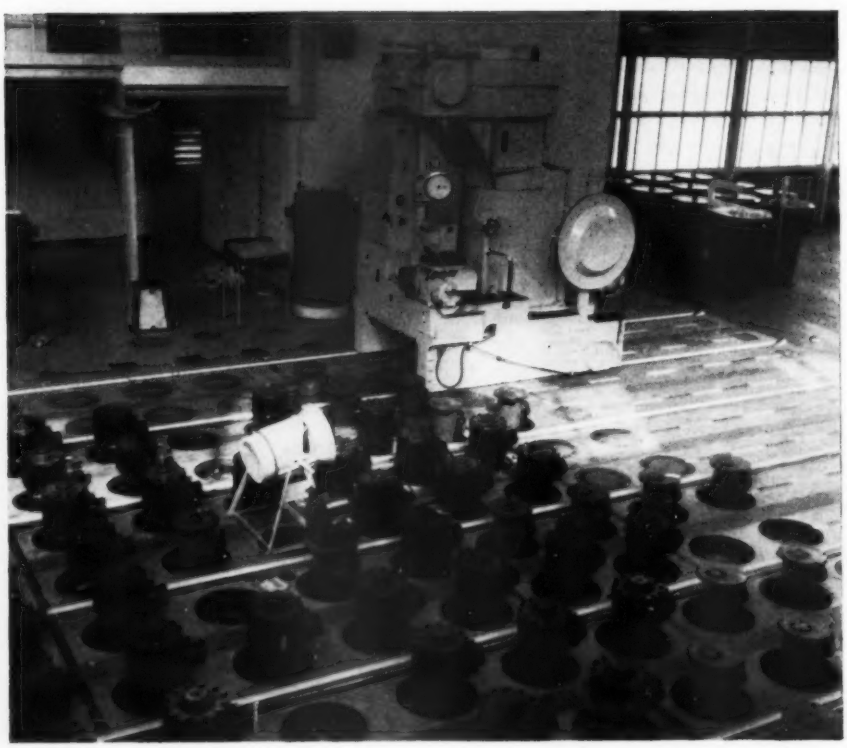
Due to the absence of oxygen or water vapour under operating conditions, oils, greases and graphite are ineffective as lubricants and, following extensive research, a dry lubricant in the form of molybdenum disulphide (MoS_2) is used in all moving parts.

The system provides for the operation of the actuators in two groups:

1 *Coarse*—up to 60 actuating mechanisms.
2 *Fine*—up to 4 actuating mechanisms.

For *Coarse* operation three control rod speeds are available:

1 In (Fast) 50 in./min maximum
2 In (Normal) 5 in./min maximum
3 Out (Normal) 0.5 in./min maximum



Sixty totally-enclosed drive units mounted in the charge tubes raise and lower the control and shut-down rods. The lighter coloured units are ion probes. A heavily shielded discharge machine is in the background: further back is a group of fuel rod magazines. Object in centre of group is portable airfan used while work is in progress

With all the rods moving together the 'out' speed limits the maximum rate of increase of reactivity to 2×10^{-6} per cent/second.

For *Fine* manual control an approximate maximum 'in' and 'out' rod speed of 50 in./min is possible. During the period of commissioning only, fast speeds 'in' and 'out' are made available by the incorporation of special test equipment.

The shut-off performance of each rod is:

1 Initial acceleration, not less than 2 ft/sec^2
2 Maximum speed, 4 ft/sec
3 A travel of 18 ft 6 in. in a time not greater than 5 seconds
4 Touchdown speed, not greater than 6 in./sec

The driving motor is of the synchronous variable-reluctance type. It has a three phase wound stator—class 'H' insulated—and an unwound rotor. This met the following requirements:

1 Synchronous operation
2 Positive holding torque at standstill
3 No brushgear in order to give greater reliability
4 High torque-to-volume ratio
5 Capable of working in an ambient temperature up to 100°C
6 Capable of running at low speed so that a small gear ratio could be employed to permit back driving by the rod during shut-off

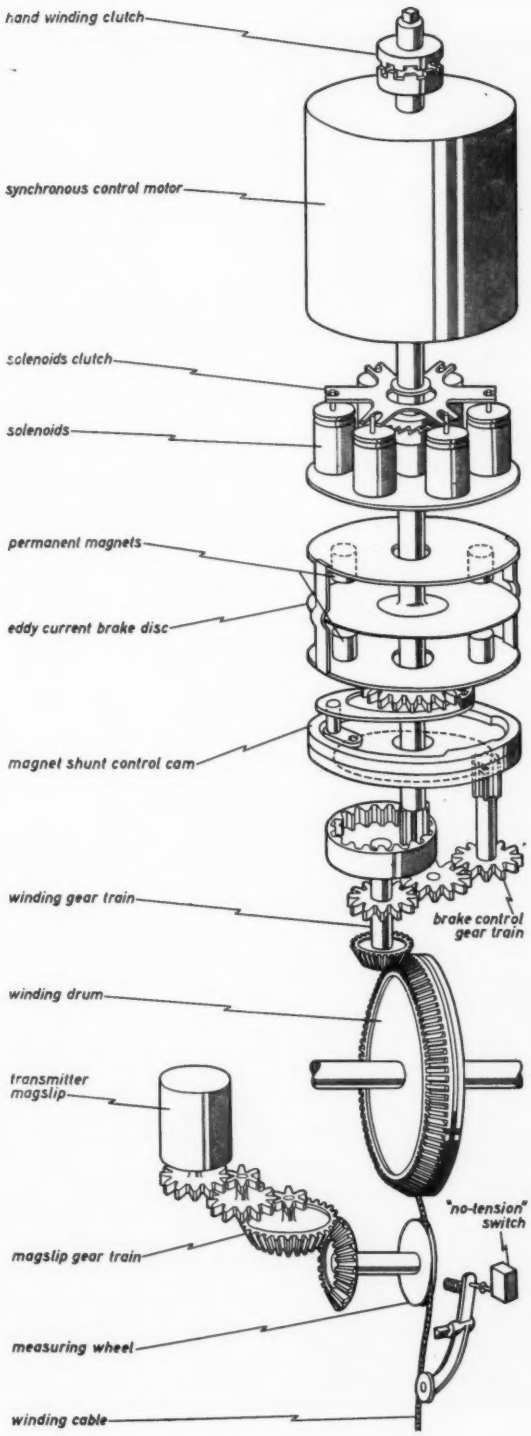
Fully controlled fall

A solenoid clutch between the motor shaft and the remainder of the mechanism disengages the rotor from the system, thereby reducing the inertia to be accelerated during shut-off. The clutch is operated by six solenoids energised from the same supply as the motor. Should the rotor fail to be disengaged when the supply is opened, a shut-off action still results due to the de-energised motor being back driven. If there is loss of drive, an emergency winding handle can be attached which mechanically engages the clutch.

To give the rod a controlled fall, an eddy current brake is fitted, consisting of two sets of permanent magnets with alternate N and S poles and a copper-clad steel disc rotating in the air gap between the magnets. The braking torque on the disc is controlled by varying the air gap magnetic flux with a magnetic shunt mechanically operated from a cam. The correct rate of fall under shut-off conditions is programmed by the profile of the cam. The performance of friction brakes was considered too uncertain and permanent magnets were chosen to make the operation independent of electrical supplies.

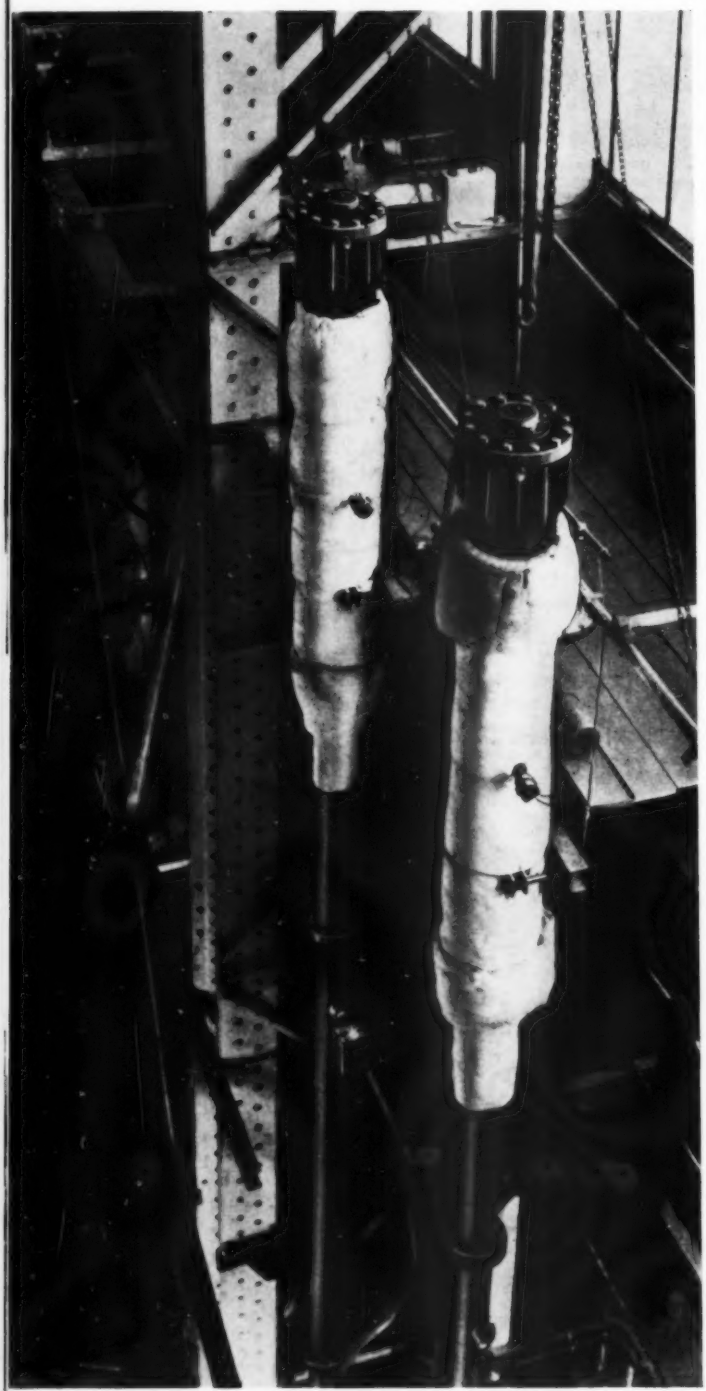
Tests under working conditions

Drive from the motor is via single-stage spur gearing and right-angled bevel gears, giving a total reduction of 20:1. Rod position indication is provided by a transmitter magslip driven by a gear train from a cable-driven measuring wheel. A lever-operated switch with a 'follower' wheel on the winding cable detects 'no-tension'. This switch is used in conjunction with a second switch operated by the magnet shunt control cam to detect 'overrun or lost rod'. The second switch is also used to check that the cam is correctly set.



Rods are hoisted by a variable-frequency synchronous motor through gear trains. An eddy-current brake and solenoid clutch give controlled gravity shut-down

Frequency and phase control rod speed and direction



Final test on actuators at the works completely simulated reactor heat and pressure conditions

After tests had been completed on individual components, endurance tests were carried out on two actuating mechanisms in an atmosphere of pure dry CO_2 with not more than 0.01 per cent by volume O_2 impurity at a pressure of 100 lb/sq in. The actuators were seated on test pressure vessels and lagged to simulate the thermal effects of the biological shield with heating equivalent to the heat flow up a charge tube. The units were run for successive tests at the highest rod speed of 50 in./min and reversed automatically at the top and bottom of the rod travel. The following main points were studied:—wearing properties of MoS_2 treated gears and bearings, temperature rises, effects of thermal cycling, and the functional operation of components. Special measuring techniques were developed to obtain this information without opening up the actuating mechanism.

Coarse and fine

The control rods are raised and lowered by the variation in frequency and phase sequence of the three phase a.c. supplies to the actuator drive motors. A range of frequencies 0 to 1.3 c/s with a constant voltage of 40V r.m.s. is employed. The zero frequency condition is used for 'holding' the rods.

'Coarse' and 'fine' control supplies to any of the units are selected by means of changeover switches mounted in distribution cubicles. These switches are connected to the main and auxiliary busbars to which are fed 'coarse' and 'fine' supplies respectively.

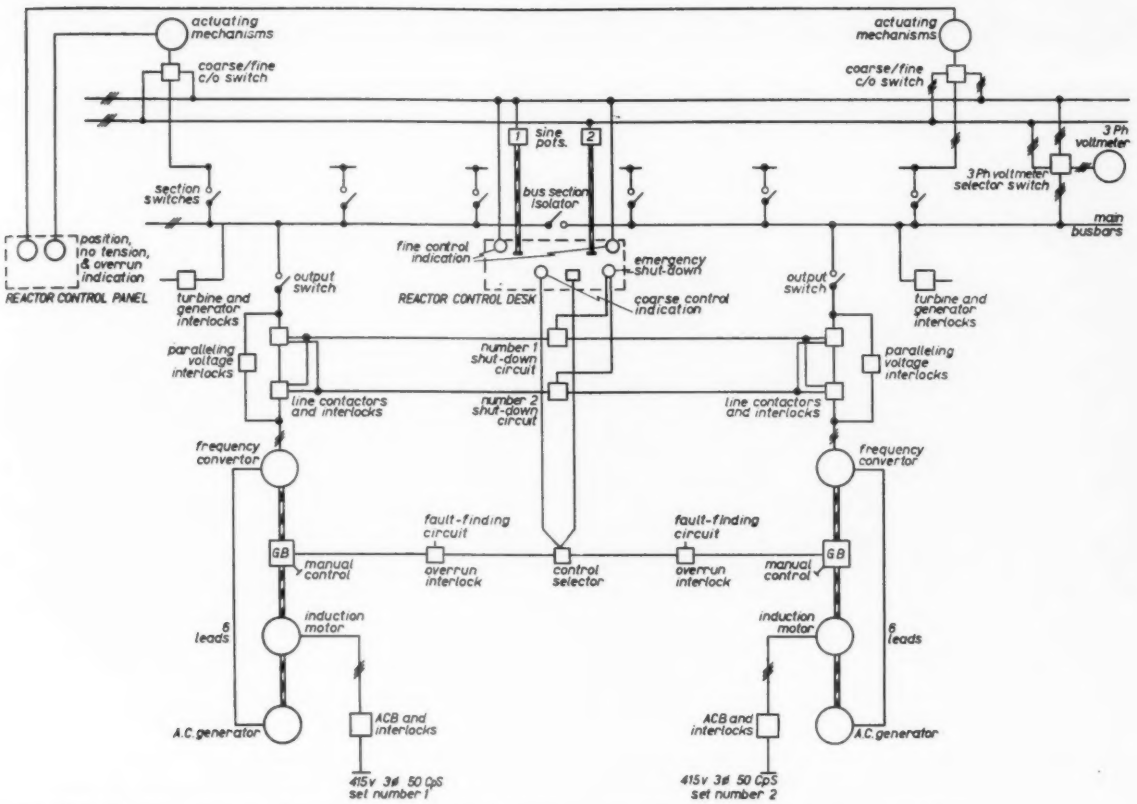
The coarse supply is generated by two (one standby) frequency convertor sets controlled from a machine operator's control desk. Position control of the 'coarse' rods 'en bloc' is provided by a control switch and magslip indicator giving rod travel which is transmitted from the frequency convertor set.

'Fine' control supplies are provided by two sine-potentiometers mounted in cubicles. These are basically resistors, chain-fed by d.c. and tapped to give sinusoidal distribution of potential. The tapping points are taken out to studs on a faceplate from which three sets of brushes pick off an output three-phase supply at a frequency equal to the rate of rotation of the brushes. Position control of the 'fine' rods is carried out at the reactor control desk by means of manual drives to the sine-potentiometers. Rod travel is given by 'M' type indicators operating from the outputs of the sine-potentiometers.

How frequency is varied

Each frequency convertor set consists of a 37.5 h.p. induction driving motor, a 22kVA salient pole a.c. generator; a differential gearbox and a 19.4kVA frequency convertor mounted in line on a common bedplate. The motor delivers full-load torque even if the terminal voltage falls to 50 per cent of its normal value and the generator is excited from the 50V station battery. This enables the set to maintain its output for the maximum time after a fault in the 415V a.c. supply.

The frequency convertor has no stator winding, is rotor fed and gives a three-phase output of 40V r.m.s. with frequencies 0 to 1.3 c/s. Input from the a.c. generator is taken to the rotor through six sliprings and a three-phase output is taken from brush arms



Simplified, this circuit shows how fine and coarse control is provided to two actuators

arranged around the commutators. The power (only friction and windage losses) is supplied by the induction motor through the differential gearbox. If the input and output shafts of the gearbox are rotating at the same speed, the frequency convertor is running in synchronism with the a.c. generator and the output derived from its commutator is of zero frequency. The values of current drawn from the three output brushes will depend on the positional relationship between the rotors of the two machines. If a decrement of speed is fed into the differential gearbox through its pilot motor section (described later) the frequency convertor runs sub-synchronously with respect to the a.c. generator and a three-phase supply can be drawn from its commutator of frequency corresponding to the difference in rotational speeds of the two machines. If an increment of speed is fed into the gearbox the frequency to the a.c. generator; again a three phase supply will be available at its commutator with a frequency corresponding to the difference in rotational speeds of the machines but having a phase sequence which is the reverse of that obtained with sub-synchronous running. The output voltage is independent of the frequency convertor speed and is determined purely by the a.c. generator excitation.

Failure to safety

The system is designed to move the rods 'in' when the frequency convertor is running sub-synchronously so that in the event of a failure of drive to the frequency convertor the system will fail to safety by moving the rods 'in'.

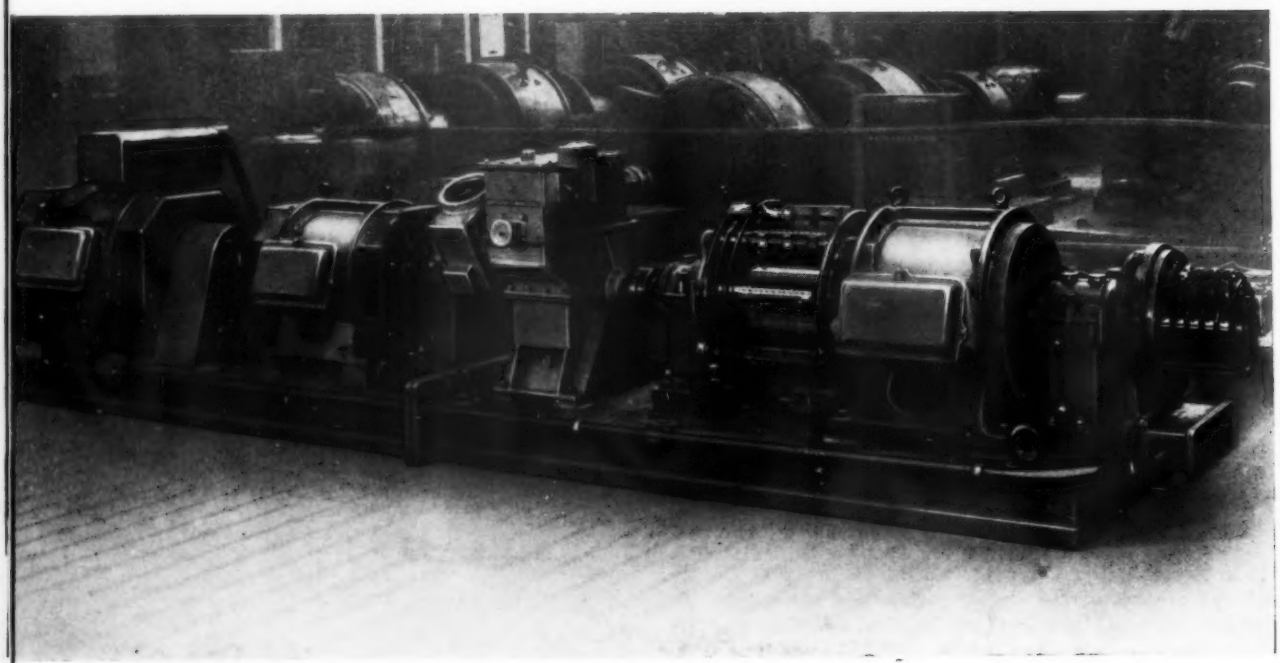
Any normal three-phase relationship between the zero frequency voltages at the frequency convertor output terminals can be achieved when the machine is running synchronously by operating the differential gearbox to bring the rotors of the a.c. generator and frequency convertor into the correct relative position; this relationship is partly dependent on the load.

Interlocks ensure paralleling

The differential section of the gearbox is of the sun-and-planet epicyclic type. Drive to the third member of the differential is through an irreversible worm from a small pilot motor via one of three permanently meshed gear ratios selected by individual electromagnetic disc clutches having stationary windings. An electromagnetic brake is applied to the third member shaft when no drive is selected by the coarse control switch on the reactor control desk. An indicating dial attached to the main gearbox housing indicates the position of the differential cage which can be manually moved over a restricted angle to facilitate paralleling of the two frequency convertor sets during changeover. Indication of the coarse rod travel is also transmitted from the differential gearbox to the reactor control desk.

In order to ensure continuity of the coarse control supply at the main busbars during changeover of the sets it is necessary to parallel the incoming set before

Scram button shuts down whole plant in emergency



The frequency convertor sets include: driving motor, generator, differential gearbox and frequency converter on same base plate

Fine control supplies come from these sine-potentiometer cubicles

transferring the load. The line contactors are interlocked to ensure correct paralleling of the incoming set, and the control selector switch is automatically interlocked so that the incoming set must be carrying the load before the outgoing set is tripped off the main busbars.

Rod positions shown

A magslip indicator in each actuator shows the rod position. The indicator also carries two lamps warning 'no-tension' and 'lost or overrun rod', operated from the switches in the actuating mechanisms via fault-finding relay circuits.

Two safety circuits detect the following:

1 Faults which necessitate de-energising the actuating mechanisms and dropping the rods, so initiating a shut-down of the reactor

2 Faults which prevent further movement of the rods

An emergency shut-down of the reactor is initiated from the 'scram' button on the reactor control desk or from one of the shut-down circuits. All the line contactors and 415V circuit breakers are opened, thus removing the control supply from the main busbars and thereby de-energising the actuating mechanisms so that the rods give shut-off action. At the same time, the sine-potentiometer supply is tripped so that the fine rods also give a shut-off action. The main turbines and a.c. generators are tripped from relays operating on under-voltage at the main busbars so preventing the turbines being motored. Hence a complete shut-down of the plant occurs.

1696 fuel channels monitored every 27 minutes for burst slugs

FUEL ELEMENT FAULT DETECTION

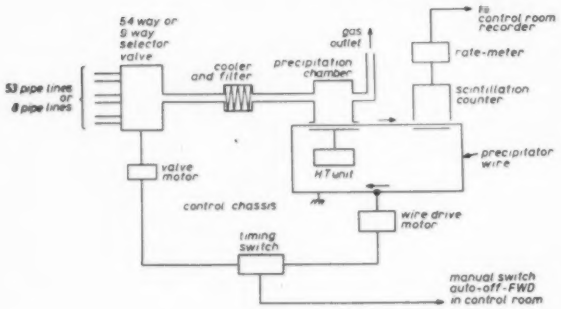
FAILURE TO DETECT A PUNCTURE in any one of the 10,000 canned uranium fuel elements could lead to the escape of fission products into the coolant stream and so spread radioactivity throughout the core and heat exchange system. The first warning of an impending fuel-can failure is the appearance of a pin-hole puncture through which fission products can escape and by monitoring a very small proportion of the gas coming from each channel an early indication can be obtained of a burst in its early stages. At Calder Hall this is done by sampling the gas coming from groups of four channels: if an abnormality is noted in the group, the four individual channels can then be tested separately and the search thus narrowed to the six elements in a particular channel.

The principle of the detection system used is the electrostatic precipitation onto a wire, of radioactive daughter products resulting from the decay of gaseous fission products. The wire is then monitored under a scintillation counter.

From each of the 1696 fuel channels in the core, a ½in. diameter stainless steel tube runs to the detection equipment. For the purpose of detection, the core is divided into eight zones and the tubes from each, in bundles of 212, are welded into a stainless steel plug welded into a branch on the pressure vessel wall.

Emerging from the biological shield, eight groups of 212 stainless steel tubes carry samples of gas from each of the fuel channels to the electrostatic precipitation units. Here are four of the groups

The Calder gas sampling system is applied both to the fuel channels and also to the bulk coolant outlets and inlets. The schematic shows the principle



They then pass through the thermal and biological shields to manually-operated cocks which reduce the number of sampling points to 53 per zone by combining them in groups of four.

Each of these 53 lines now passes to a motor-driven 54-way selector valve which in turn links each to one of eight precipitator units situated in a special room above the reactor control room. Samples from each group of four channels is taken every 27 minutes, the valve remaining stationary at each inlet for 28 seconds and taking 2 seconds to travel between ports.

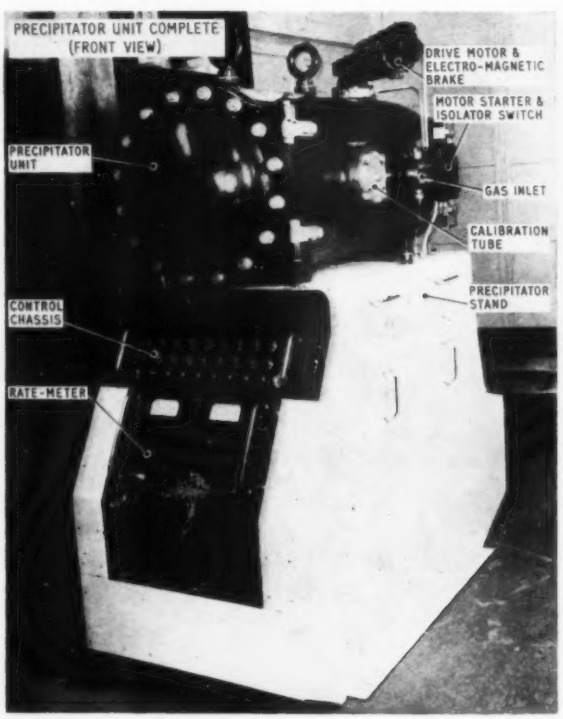
The selector valve consists of a body with 53 inlet ports, the 54th position having an internal transport port which maintains gas flow through the valve. The inlet ports are connected in turn with the outlet by means of a rotating transfer port driven by a motor through a worm drive and free-wheel. As the rotor arm approaches an inlet port, a cam mechanism fitted to the housing snaps it forward into the correct position, the free wheel mechanism preventing damage to the motor. The motor is then switched off by a valve switch, rapid stopping being provided by an electromagnetic brake. Remote indication of the valve position is given in the control room by means of 54-way dial indicators connected to synchros on the selector valves.

On leaving the selector valves, the gas sample is passed first to a cooler unit and then to filters before delivery to its precipitator. These filters remove any particulate fission products—which have long half-lives—leaving only gaseous products remaining. Some of these quickly decay and can be precipitated electrostatically.

The precipitator units consist of a horizontal cylindrical casting containing the wire drives, and scintillation counter. Below, are situated control chassis, e.h.t. unit, ratemeter and indicator panel. The wires are of stainless steel, 0·005in. diameter, and are motor-driven round a series of pulleys to form a continuous loop. The motor is mounted outside the unit and is fitted with an electromagnetic brake.

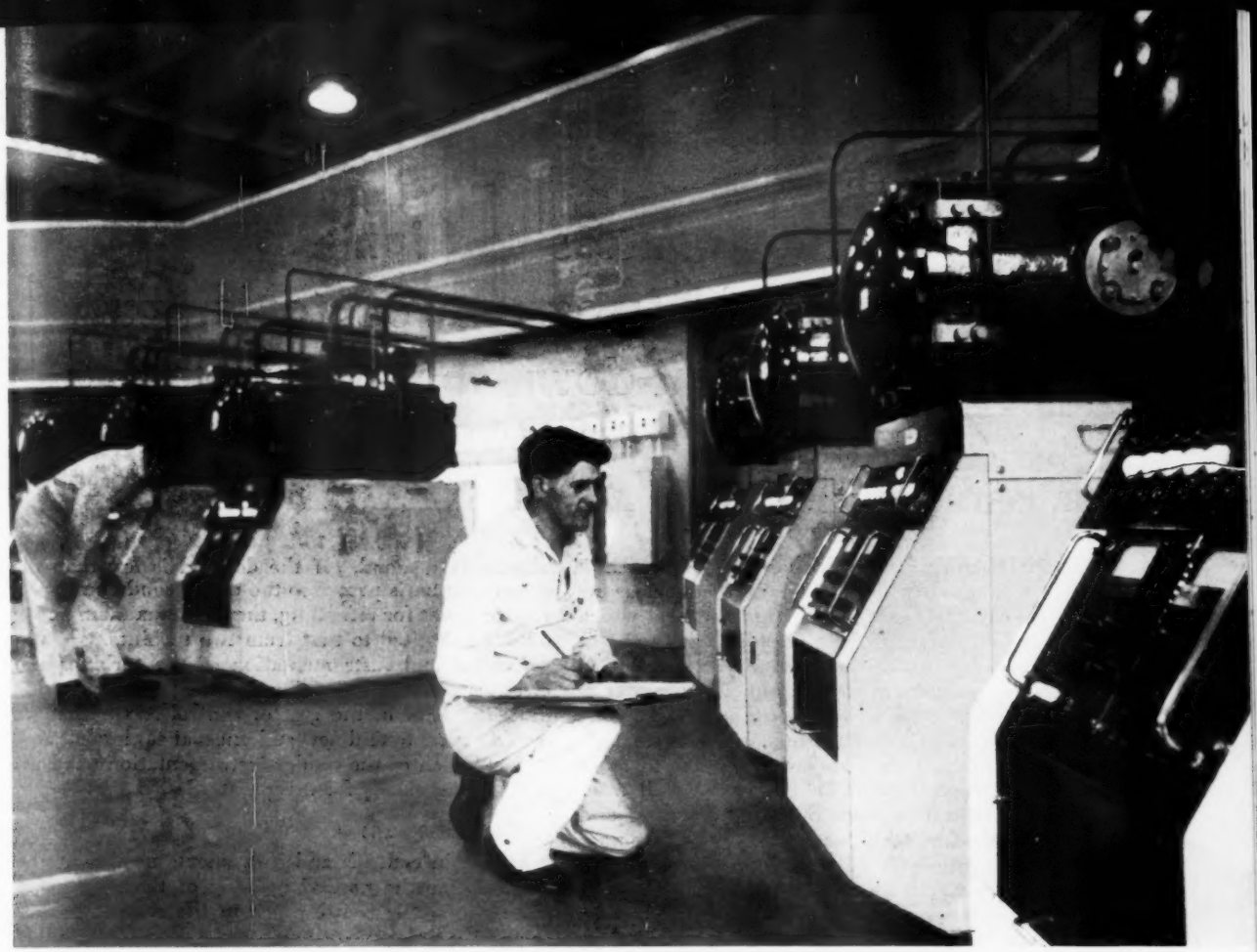
The wire is held at earth potential, the voltage of the positive electrode of the precipitator being 5kV. This causes solid decay products to be attracted to the wire which, after the 28-second sampling period,

The precipitators are under the full 100 lb/sq in. pressure and so have to be heavy castings. This also incidentally provides shielding



A total of eleven of these precipitator units are installed in each of the two Calder reactor buildings

PRECIPITATOR UNIT COMPLETE (REAR VIEW)
COOLING TUBE & PHOTO-MULTIPLIER
GAS OUTLET
ELECTRICAL CONNECTIONS TO PRECIPITATOR SWITCH & WIRE & STRAND BREAK SWITCHES
LIGHT FOR SWITCHBOARD ILLUMINATION
WATER FLOW SWITCH
E.H.T. UNIT
GAS TEMPERATURE GAUGE
GAS PRESSURE GAUGE



So important is the speedy location of a faulty fuel element that a complete control room is given over to this. Chart records are however kept and warnings given in the main reactor control room

moves along to the scintillation counter utilising a plastic phosphor concentric with the wire. Scintillations are detected by a cooled photomultiplier tube and the output passed to a ratemeter which integrates the count over the 28-second monitoring period. The output is also passed to the control room where a record is made on a set of 54-point scanning recorders (described in NUCLEAR POWER, October p 260). These have nine pens and six columns, the selection being made by a nine-way and six-way switch on each selector valve which links each fuel sampling group to a definite position on the 54-channel record.

If any abnormality is recorded by these instruments, the suspect group of four channels can be switched to a spare precipitator unit and the signal diverted to a single point recorder in the control room. If further investigation is necessary, by means of the manually operated valves, individual fuel channels can be isolated in turn until the faulty one is located. After sampling, the gas is returned to the main coolant circuit.

While a section of the wire is being monitored, the next sample is already being precipitated further along the wire. This necessitates screening between the two sections within the precipitation chamber. No portion of the wire is used more than once in 30 minutes, thus allowing long-lived activity to decay before it is used again.

In addition to the sampling from individual fuel channels, bulk sampling is also carried out from eight further points—one each in the inlet and outlet gas ducts of the heat exchangers. The reason for this is that the possibility exists of a burst immediately after a channel had been monitored. It would be nearly half an hour before its turn came round again and the bulk sampling gives an additional warning. These sampling lines lead to the inlet ports of a 9-way selector valve similar in principle to those used for fuel channel sampling. The same sampling period of 28 seconds with a 2-second transfer time means that each point is 'sniffed' every 4½ minutes. The rest of this installation is similar to that for the channel detection apparatus. There is a total of eleven precipitators: eight for the fuel channels, one for the bulk sampling, and two spares. At the time of The Queen's opening there had been no cases of burst cartridges.

The burst slug detection installation was designed by Plessey Nucleonics Ltd in collaboration with the UKAEA.

Pulse counters and ion chambers measure reactor output from shut-down to full power

THE INSTRUMENTATION

THE PRIMARY PURPOSE of the Calder Hall station is to produce plutonium in the nuclear reactors. Electricity is generated from the heat which must be taken away from the reactors, but the plant is designed for maximum plutonium production rather than optimum power output. This emphasis on the importance of the reactors is reflected in the design of the control and instrumentation system.

Each reactor has its own control room together with a third control room in the turbine hall from which the electrical output is regulated. The feed and steam systems for each reactor are kept separate and even the two sides of the electrical system are made as independent as possible, in order to reduce the chance of a single fault causing a shut-down of both reactors.

The steam supply to the four turbines is fully cross-connected so that any turbine may be run from either reactor. The principle of operation is that both reactors are kept on full load as far as possible, the turbines taking what steam is needed to meet the electricity demand. If the demand is less than the supply, steam is passed to the dump condensers: if a reactor is out for refuelling, then the maximum power output is limited to that from two turbines.

Control and instrumentation of the turbines and electrical generators follow normal power station practice. It is in the reactor control rooms that we would expect to find new and unusual equipment and, in fact, much of the Calder instrumentation has been developed specially for this plant.

Mimic diagram

The main controls and instruments needed by the operator for the normal running of the reactor are mounted on the control desk in the reactor control room. On the control panel immediately in front of the control desk is a large mimic diagram of the coolant and steam circuits, on which are mounted instruments indicating the relevant temperatures, pressures and flows.

The rate of heat generation is inferred from mea-

From the Calder power house control room, current from the four turboalternator sets is distributed according to demand. Nos 1 and 4 supply the Calder reactor buildings and power station ancillaries together with the CEA grid. The output from sets 2 and 3 is taken direct to the Windscale plutonium works where further grid supplies are taken off. Windscale switching is however done from this control room by remote control

Key to the Calder no 1 reactor control room

Burst fuel element detection gear

1 & 2 54-point recorders
3 54-point selector valve indicators
4 8-point recorder
5 8-point selector valve indicator
6 Single point recorder

Fuel temperatures

7 Multipoint temperature recorders (for both fuel elements and CO_2
8 Multipoint temperature indicator (for both fuel elements and CO_2

Heat exchangers

9 'Dew-point recorder' (i.e. steam in CO_2)
10 Single point fuel element temperature recorder
11 Heat exchanger graphic panel
12 High pressure steam flow
13 High pressure steam pressure
14 CO_2 flow
15 CO_2 pressure
16 Low pressure steam flow
17 Low pressure steam pressure
18 Fault indicator panel

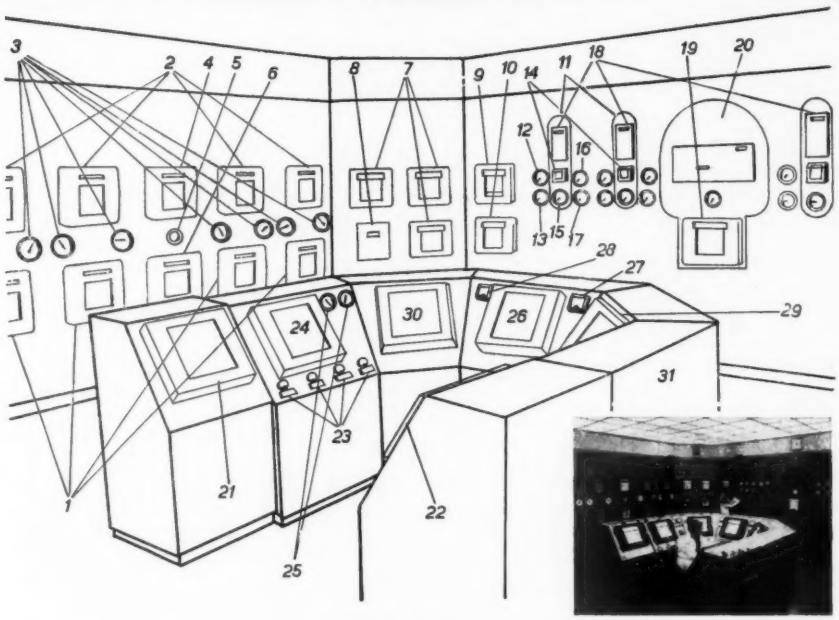
Reactor graphic panel

19 Logarithmic power level (neutron flow) recorder
20 Reactor fault indicator panel

On control desk

21 Low level logarithmic power level recorder—ion chamber, DC system
22 Low level logarithmic power level recorder—pulse counting channel

These two are in removable end sections which are pushed into place safely during the start-up of the reactor



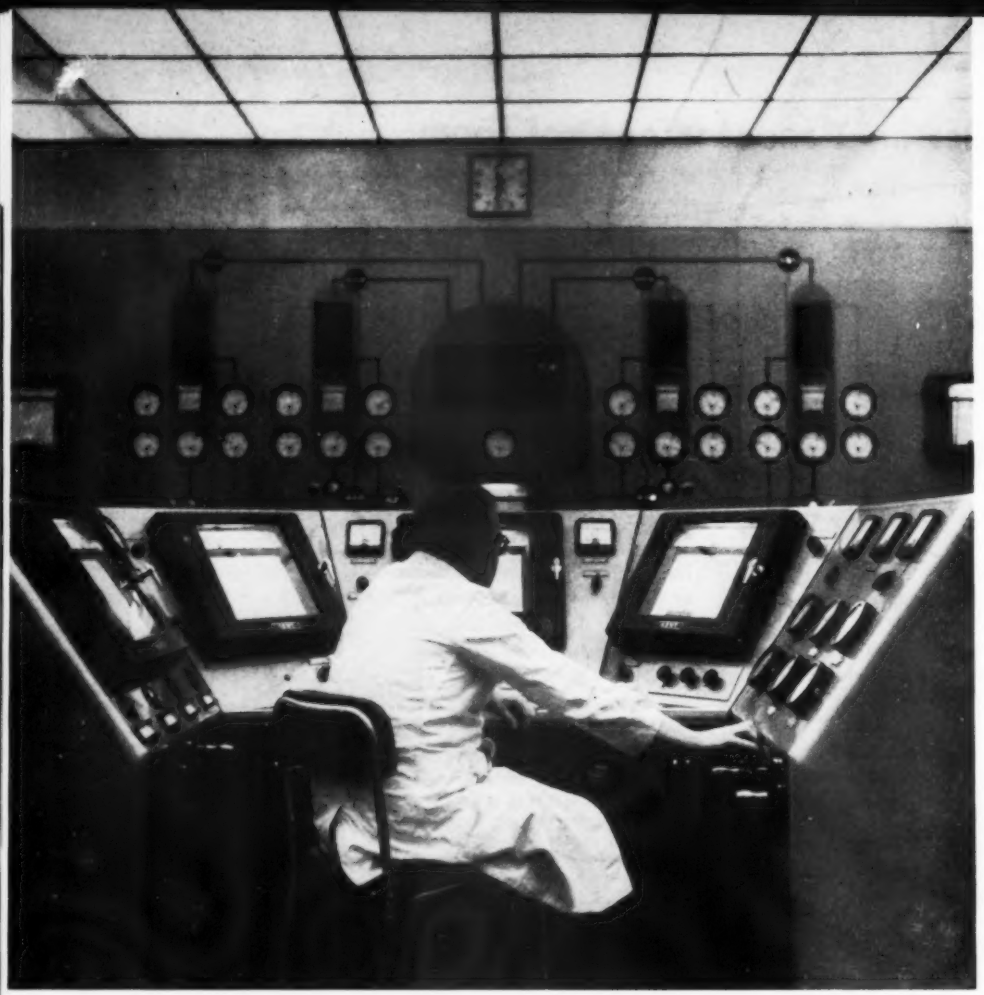
23 CO_2 circulator tachometers—with ammeters in each circulator motor circuit immediately above corresponding tachometer
24 3-point temperature recorder—2 inlet CO_2, 1 fuel element
25 Valve "B" controls (i.e. adjustment of l.p. steam pressure affected inlet gas temprature
26 2 range linear power level recorder
27 Micro-ammeter in ion chamber circuit indicating power level (0-220MW)
28 Voltmeter monitoring battery supply to ion chamber of 27 & 26 immediately under these are the illuminated push button of the internal telephone system
29 Power level "drift" recorders
30 Fuel element temperature "drift" recorder
31 This panel which operator is observing, contains the fine control rod controls and position indicators, plus reactor doubling time indicator, plus "megawatts to shut down" indicator of the main power level trips

surements of the neutron flux outside the reactor core, and is controlled by movement of the neutron absorbing control rods. The temperature rise of the coolant gas is controlled by its circulation speed and, by adjusting the pressure of the low pressure steam, the temperature of the gas returning to the reactor can be controlled.

Sb-Be neutron sources

The neutron flux must be measured at all times, from shut-down to full power. By using self-sustaining neutron sources of antimony-beryllium the range of neutron flux is reduced from about 11½ decades to about 8 decades. The neutron flux detectors are mounted in a graphite block just outside the pressure vessel. But because the pressure vessel becomes intensely radio-active, this large range of fluxes cannot be measured by a single instrument, even though two of the ionization chambers are shielded from the gamma-rays by four inches of lead. In the low power region, the power of a reactor changes exponentially with time and consequently the low power instruments are calibrated logarithmically. A pair of 'pulse-counting' instruments cover the range from shut-down to a few kilowatts, and two logarithmic d.c. amplifiers ('reactor period meters') with ion chambers measure the power from about a hundred watts to full power (i.e. about 200MW). At normal running powers the reactor is controlled from observations of the 'drift' power recorder. This is a potentiometric-type of strip chart recorder connected directly to an ion chamber and it indicates the difference between the reactor power and an adjustable 'demanded' level. A further potentiometric recorder connected directly to an ion chamber records the power level on a linear scale and is fitted with an integrator to indicate megawatt-hours.

Measurements inside the reactor are difficult because the choice of materials is restricted by chemical compatability with the magnesium fuel element



Watching the power level drift recorder, a shift foreman makes a slight adjustment to the control rods. Button on the right of his recorder in red, gives emergency scram action

sheaths, by the temperature of about 650°F, and by the damage suffered by many materials under the intense radiation. The temperatures of a dozen fuel elements are measured using thermocouples of stainless-steel-sheathed mineral-insulated cables, which are capable of withstanding such conditions.

A large number of instruments are needed to detect fault conditions in the reactor and its associated plant. Rupture of a fuel element sheath, for example, is detected by the release of radioactive rare gases into the coolant stream—this is described in detail in another article (p. 287). For emergency conditions a group of three shut-down amplifiers connected to ion chambers will bring the reactor sub-critical if the power output exceeds a level determined by the coolant mass-flow. These amplifiers are interconnected so that two out of the three must operate simultaneously to produce a shut-down: one operating alone—possibly due to a fault in the amplifier itself—merely sounds a warning.

Neutron flux distribution

Because of the great difficulty of any maintenance work on the heat exchangers, corrosion must be reduced to a minimum; this demands an unusually high degree of feed-water purity. The determination of pH and dissolved solids follow normal practice but the specification limit for de-aeration of 0.005 cc/litre precludes the use of the normal catharometer type of instrument. A new type of instrument has been developed for this purpose using a polorographic technique. This has a full-scale sensitivity of 0.035 cc/litre.

A leak in the low pressure section of the heat exchanger allows contamination of the water by CO_2 whilst a leak in the high pressure section allows water to contaminate the CO_2. A by-pass drier on the CO_2 circuit is capable of removing $2\frac{1}{2}$ lb of water per hour at a concentration of 0.03 per cent by weight. A leakage rate above this level would accelerate corrosion of the heat exchanger. An instrument of the infra-red gas analyser type is provided which has a full-scale sensitivity of 0.02 per cent. water in CO_2. Both the measuring cell and the reference cell, which contains dry CO_2, have thick calcium fluorite windows capable of withstanding 100 lb/sq.in. The measurement of CO_2 in steam also uses an infra-red gas analyser but the steam must first be condensed. Any CO_2 is stripped from the condensate by air, which is then passed to the measuring cell. This reference cell contains dry air free of CO_2. The full-scale sensitivity is 1.0 cc of CO_2 per litre of condensed water.

The distribution of neutron flux throughout the reactor is measured by dropping lengths of tungsten wire into the reactor. After about half-an-hour they are removed, the intensity of radioactivity along the wire as measured by an ion chamber, indicating the distribution of neutron flux.

Windscale factory will now get its power from Calder

ELECTRICITY GENERATION AND DISTRIBUTION

THE FOUR ALTERNATORS have a maximum continuous rating of 23MW at a power factor of 0.8 lagging. These are of normal Parsons two-pole design for 3000 rev/min and generate at 11.5kV. Air-cooled exciters and pilot exciters are directly coupled and are fitted in common frames. The alternator is air-cooled by a closed circuit system supplied by a pair of motor-driven fans mounted in recesses in the alternator foundation blocks.

The output from all four generators (it will not be possible to run them simultaneously until no 2 reactor is working—*i.e.* in about six months) is not dealt with in the same way. Sets 1 and 4 are distributed from Calder Hall itself and supply all the station ancillaries, such as blowers and pumps. This will amount to some 16 to 20 megawatts when both reactors are working at full power. The balance of installed capacity will be available to the CEA Grid through a pair of 30MVA, 11/132kV tap-changing transformers in a compound just outside the administration block.

The output from the other two turboalternator sets (nos 2 and 3) is taken direct at 11kV to a switchhouse at the Windscale plutonium works. Here, current is taken for driving the several blowers which cool the two large graphite piles and the balance is passed into the Grid through the substation which was built originally to bring grid power into the works.

The neutrals on each set are earthed through a circuit breaker and resistance when the sets are not supplying the Grid; but when they are paralleled, earthing is done through an earthing transformer and resistance coupled to the 11kV side of the Grid transformers.

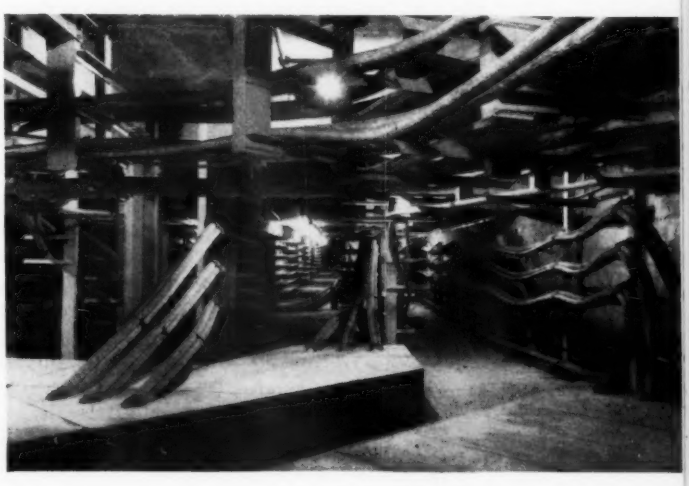
Output from sets 1 and 4 is taken to two switchgear banks situated in a room below the control room. These comprise three 500MVA rupturing-capacity oil-break horizontal-draw-out circuit-breakers by Reyrolle controlling a generator, a grid transformer and an 11kV feeder to each reactor house. This 11kV supply is for the Ward-Leonard motor-generator sets which provide d.c. for the gas blower motors and it is taken through Bryce 30MVA current-limiting reactors to English Electric 350MVA metal-clad, compound-filled, horizontal-draw-out, oil-break switchgear situated in the reactor buildings. These are 13-panel units, five of which have a 1600 amp rating and eight 400 amp. Associated with each set are a 1-15 circuit control and relay board in the main reactor control room.

Supply to ancillaries is at two voltages, 3.3kV and 415V, and is obtained through a battery of station step-down transformers situated in open pens along the east side of the turbine hall at ground level. Air-break switchgear used for distributing these supplies is of English Electric manufacture, the 415V gear having a maximum rating of 1600 amp, while the 3.3kV breakers are rated at 800 amp with a 150MVA fault rating.

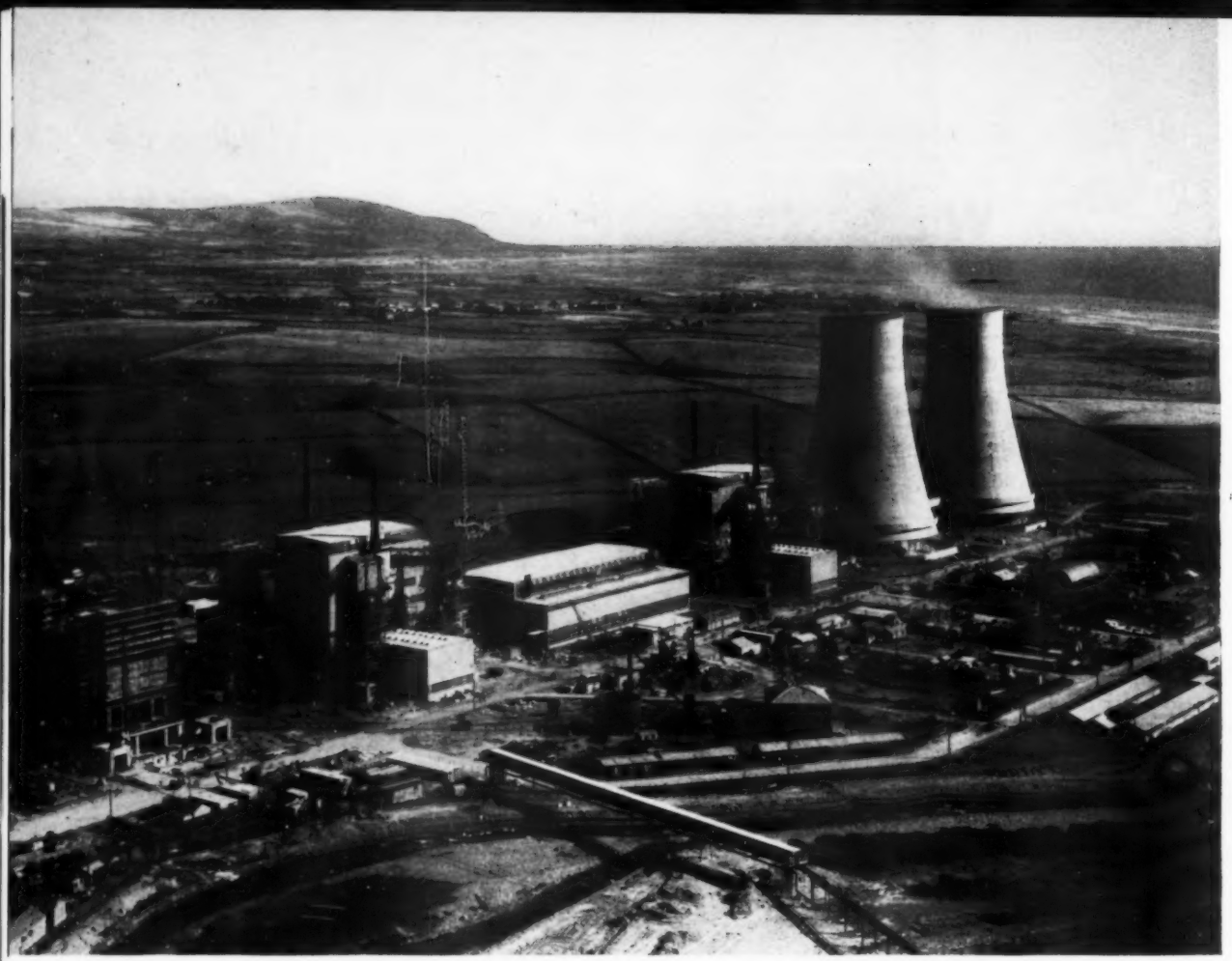
Control rod drives, fans, cranes and other ancillaries in the reactor complex are run from 415V supply and for these purposes 13-panel units are installed. In the turbine hall for feed pumps, extraction pumps and other services both 3.3kV and 415V are used. There are two 3.3kV switchboards—one of 14 and the other of 15 panels—and two 8-panel boards for the lower voltage.

Power for the five circulating pumps, situated in a concrete pit close to the cooling towers, is supplied at 3.3kV through a 13-panel board in a local control house.

The Windscale supply from sets 2 and 3 is taken direct at 11kV 1100 yards to the new switchgear within the factory perimeter. This houses two 3-section



In the cable basement at Calder, three tunnels branch out. Right and centre, rising from brick chases, two sets of 11kV cables run to the Grid transformers in the CEA compound. Left, rising from the chase, lines from no 2 generator set run to Windscale down left hand tunnel. Entering right hand tunnel some way down, 11kV feeders take power to the reactor buildings



Power from Calder Hall is brought to Windscale through eighteen single-core cables carried by a bridge over the river Calder. To the left, one of the two reactor houses of Calder Hall B is already in an advanced stage of construction

750MVA rupturing-capacity switch units which control a generator, a Grid transformer and an 11kV feeder to the factory. This switchhouse is normally unmanned and is managed from the Calder control room by remote control circuits. The power and control cables, by British Insulated Callender's Cables, lie in a trench for most of the route but cross the River Calder on a new 250-ft footbridge. Eighteen 11kV single-core cables laid in trefoil formation bring the power to Windscale and following the same route are also eighteen multi-core cables for the control circuits.

Control switchgear at Calder is of the corridor type —instruments, controls and mimic diagram on the front panels with the relay cubicles behind. All four generators are controlled from here—nos 1 and 4 directly and nos 2 and 3 indirectly at Windscale through 50V d.c. miniaturized remote control circuits. The operational control board in the centre of the room has overriding control to the generators, essential instruments and also tap-changing controls for the grid substations at Calder and Windscale.

Busbar zone protection is provided for the metal-clad switchgear and the high-impedance system used gives protection against both phase- and earth-faults.

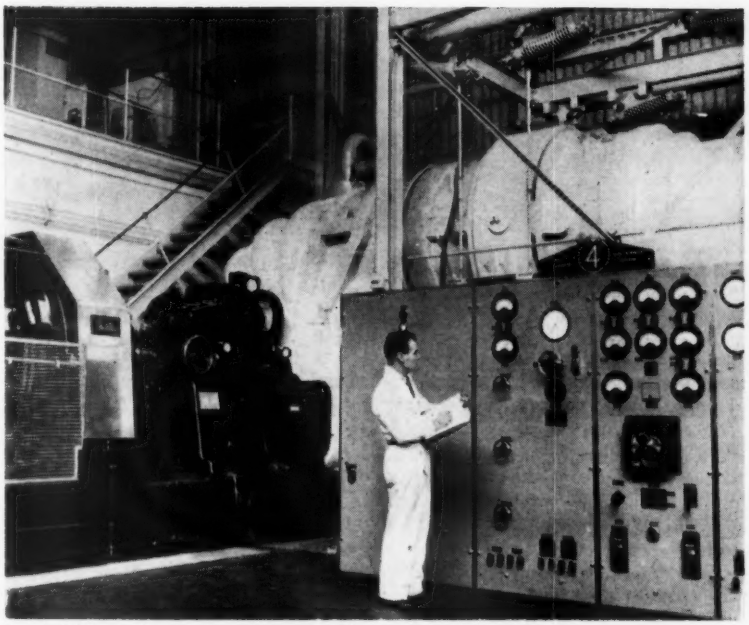
Originally, Windscale took power from the Grid and when the factory was built a 132kV line was run from Roosecote power station, Barrow-in-Furness. Now that current will be supplied from Calder Hall the original 11kV feeder from the substation has been cut and re-routed through current-limiting reactors to the new switchhouse so that supplies may now be fed into the Grid at this point. The 132kV line also now runs north to Carlisle and this is tapped at Egremont and Stainburn from whence supplies at 33kV are taken to the industrial areas of Workington and Whitehaven.

For emergency supplies to the reactor buildings, in which a complete power cut could have serious consequences, a standby battery room is provided in the power house. This contains two Chloride 120-cell Planté batteries. The cells are in lead-lined wooden boxes and the batteries have each a capacity of 1950Ah at the 10-hour rate. A 400kW mercury-arc rectifier provides a trickle charge across the batteries of 2.25V per cell. Two eight-cylinder Crossley diesel-electric standby generator sets are also provided in what is known as the 'long' blower house of each reactor.

Ward Leonard for CO_2 blowers gives 10:1 speed ratio

The eight main gas circulators (four to each reactor) are driven by separately excited light compound-wound direct current motors with commutating poles and pole face compensating windings. These motors were supplied by Mather & Platt Ltd, under a sub-contract from C. A. Parsons & Co Ltd. Each motor is continuously rated at 0/1500/2200 h.p., when running at 0/854/940 rev/min, and with the armature supplied with current at a voltage of 0/540/600. The motors are designed for speed regulation on the Ward Leonard principle by variation of the armature voltage over a range of 10:1.

Each motor is supplied by a motor generator set also of Mather & Platt manufacture. The generator is continuously rated for an output of 0/1190/1730kW at 0/540/600 volts at a full load speed of about 740 rev/min. It is of the direct current, separately excited, shunt type, with commutating poles and pole face compensating windings. The driving motor of the motor-generator set is a squirrel-cage induction motor, direct-on started, continuously rated for an output of 2500 b.h.p., when running at about 740 rev/min, and connected to a 50 cycles, 3 phase, 11,000 volt supply. The excitation for the d.c. motor and generator is obtained from two exciters each rated at 4kW 220 volts and arranged to be driven by a flexible coupling from the commutator end of the generator shaft.

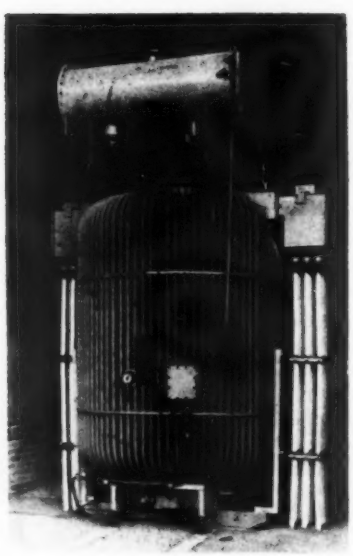


In each blower house are two gas circulators. Over the reduction gearing is a pony motor for barring round the blower

A control panel with all the necessary instruments and controls was also supplied by Mather & Platt for each motor driven circulator.

Mather & Platt Ltd, Park Works, Manchester 10

Current-limiting reactors protect plant against faults



One of the 30MVA Bryce reactors at Calder

The effect of short circuit currents in a power circuit can be minimized by an increase in the percentage reactance in network at the instant the fault occurs. This is achieved by means of current limiting reactors placed at strategic positions in the network, and arranged in such a manner that they do not cause a large voltage drop during normal operation, but prevent excessive currents being fed into the fault by the alternator when a fault occurs, thus protecting the generating plant from serious damage.

At Calder Hall two Bryce current limiting reactors were supplied, these being connected in the main 11kV feeders. These reactors are of the oil-immersed, self-cooled type provided with magnetic shielding, each unit having a rating of 30MVA and reactance of 8 per cent and designed to withstand a fault current of 9,200 amperes.

In addition to the reactors Bryce also supplied two 3000kVA and two 4000kVA transformers to supply the power station auxilaries. Numerous transformers were also supplied to the Windscale Works.

Bryce Electrical Construction Co Ltd, Kelvin Works, Hackbridge, Wallington, Surrey

Mechanical services

In the mechanical erection and construction work at Calder, Matthew Hall shared in the installation of: thermal shielding, graphite laying and support features, burst cartridge detection system, ventilation, plant erection, mechanical services, pipelines and charge tube cooling assemblies.

Matthew Hall & Co Ltd, Dorset Square, London, NW1

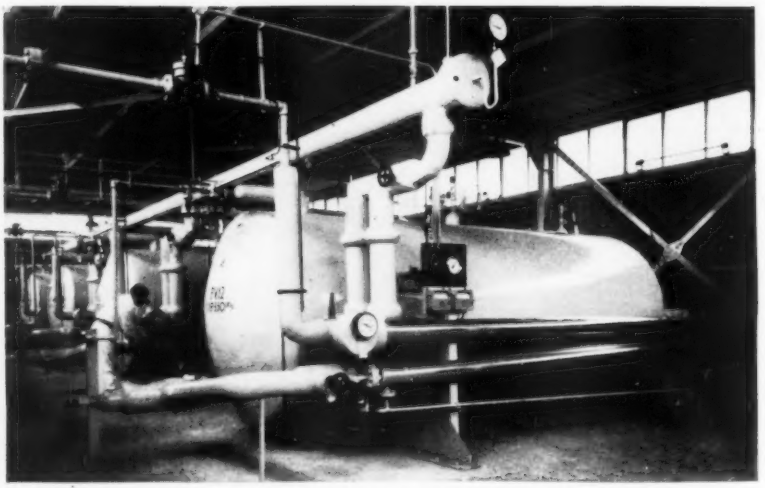
Liquid CO_2 arrives by road tanker; evaporated by steam

Cooling of the graphite-moderated reactors at Calder Hall and the transfer of heat from the reactor to the steam-raising plant, is achieved by forced circulation of pure carbon dioxide gas at 100 lb/sq in. in a closed circuit through the reactor and the steam-generating heat exchangers. The total amount of carbon dioxide in the system is considerable, and the supply of gas, both for the initial filling and for normal operation, presented a number of special problems.

Large-scale uses for carbon dioxide already exist in the bottled drinks industry, and many industrial fields. The total usage at Calder Hall necessitates considerable reserves on site, and the only satisfactory method of supply which met all the requirements is bulk delivery and bulk storage of liquid carbon dioxide, introduced into this country in 1949 by The Carbon Dioxide Company, a division of The Distillers Company Ltd.

The Calder installation, supplied and erected by the company, is the largest plant of its kind so far built in the British Isles. It consists of four insulated steel tanks, in which a total of 22 tons of liquid carbon dioxide may be stored. Each tank is fitted with an automatic pressure-controlled refrigerator, which cools the liquid to about 0°F. and maintains the pressure at 300 lb/sq in.

The storage tanks are filled by bulk deliveries in the company's standard road tankers, which carry four tons of liquid at sub-zero temperatures under pressure. The vehicles are filled at one of the many factories of The Carbon Dioxide Company situated throughout the country, and are discharged at Calder Hall by means of an electrically-driven transfer pump on the vehicle. This pump is powered by a generator coupled to the tractor engine.



Over five tons of gas are stored in each of these tanks. When needed it is evaporated in the tubular heater alongside

Filling or emptying a tanker takes approximately one hour and is carried out without interrupting normal working of the plant.

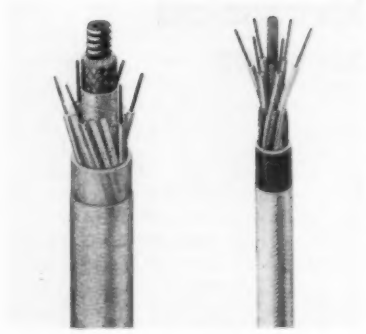
For use in the reactor circuit, the liquid carbon dioxide is vaporized in four specially-designed evaporators, developed and constructed by the DCL Research and Development Department in conjunction with the engineers of the Atomic Energy Authority. The evaporators consist of two parallel banks of steam-jacketed tubes, the number and size of which were calculated to meet the maximum demand of the system. Each unit can vaporize more than two tons of carbon dioxide an hour. The units are coupled to a manifold, giving a total output of over eight tons an hour when the main circuit is being filled or purged. The same system supplies the smaller quantity of carbon dioxide gas required for normal operation.

Constant control is exercised during manufacture of the carbon dioxide, and the system of bulk delivery and bulk storage ensures that there is no loss of quality before the very pure gas is fed into the reactor system.

The greater part of the installation consists of standard equipment whose efficiency has already been established in general use. The special modifications in design and material required to meet certain unusual features in the Calder Hall specification have proved very satisfactory under test and have made the system completely reliable in this latest application.

The Carbon Dioxide Co, Devonshire House, Piccadilly, London, W1

Electric, pneumatic circuits integral in fuel hoist cables



BICC, in conjunction with Strachan & Henshaw Ltd, have developed two new types of cable for use on thermal reactor charging and discharging machinery. These cables are capable of withstanding the high temperatures and radiation encountered by the grabs used to handle the reactor fuel rods without failure or loss of electrical performance. The first type, of which over forty length are being supplied, contains six 19/·0076 nickel plated copper P.T.F.E. insulated cores laid around a central 110-ton quality steel strand and is used at Calder Hall for the electrical control of the reactor charging and discharging grabs. The second type, which is being installed experimentally at Calder Hall, incorporates a flexible central duct in addition to the electric wires, and enables electro-pneumatic control to be achieved with the use of only one flexible cable.

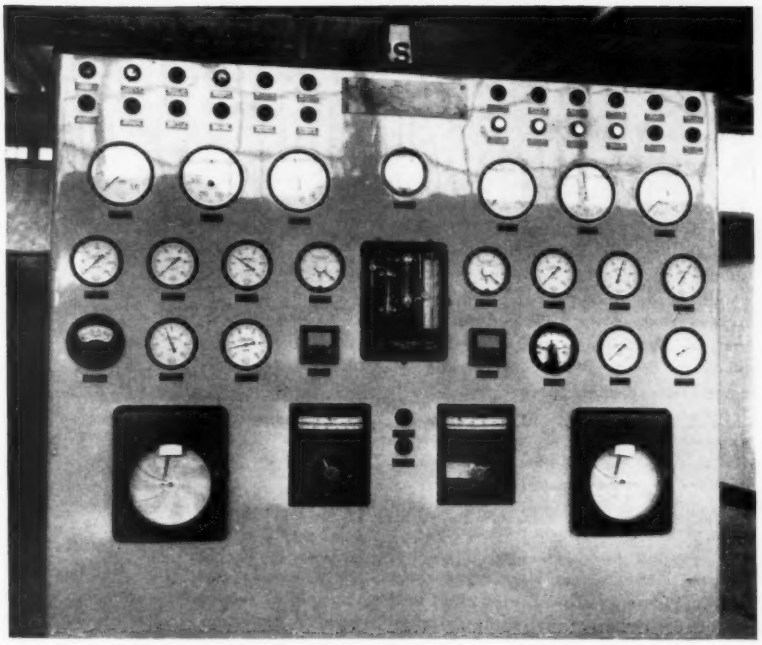
Hoist cables with electric wires (right), with central pneumatic line (left)

British Insulated Callender's Cables Ltd, 21 Bloomsbury St, London, WC1

Strachan & Henshaw Ltd, Steel-hoist Works, St Philips, Bristol 2

Dissolved oxygen by electrochemical instrument

In order to reduce to the absolute minimum any risk of stress corrosion in the water circuit, special instrumentation is in use at Calder to record the concentration of dissolved oxygen in the water. This is carried out by Cambridge electrochemical dissolved oxygen recorders which are capable of detecting concentrations far smaller than can be measured by the physical type of apparatus. The recorder depends on the principle that a small potential applied between two electrodes immersed in water which has been rendered conducting will produce a current depending on the concentration of reducible substances present. The value of the potential determines which substances will produce a current. By using two cells with different potentials it is possible to obtain two currents, one of which is proportional to the concentration of certain impurities and the other to the same impurities plus dissolved oxygen. The difference, which is recorded, is thus a measure of oxygen only. In practice, a small amount of cooled feed water is continuously dosed with salt to make it conducting and then passed by the two pairs of electrodes which are of silver and mercury. A chart recorder indicates directly the oxygen concentration and a simple calibrating device forms an integral part of the instrument.



A turboalternator instrument board shows in bottom row (centre), Cambridge multipoint distance thermometers

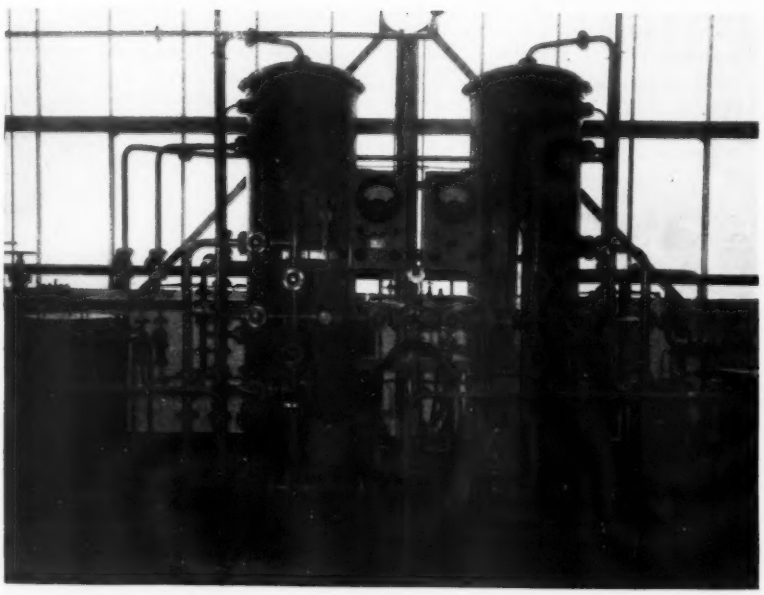
Other Cambridge instruments used: multi-point stator temperature indicators for the alternators, multi-point distance thermometers, and chart recorders.

Cambridge Instrument Co Ltd, 13 Grosvenor Place, London, SW1

Ion exchange plant for feed treatment

Two Permutit *Deminrolit* mixed bed water treatment plants are installed at Calder Hall. Each unit has a throughput of 2,200 gal/h and provides treated water with a conductivity of less than ·1 reciprocal megohms and a silica content of not exceeding ·2 ppm. Each unit contains a bed of intimately mixed Permutit cation and highly basic anion exchange materials. When raw water passes down through this bed the mineral salts present in the raw water are converted to their equivalent acids by the exchange of hydrogen ions from the cation exchange materials. The acids are then absorbed by the anion exchange material. When the exchange capacities of the materials in the unit require replenishing the cation exchange materials are regenerated with sulphuric acid and the anion exchange materials with caustic soda. The vacuumatic acid handling system enables the acid to be drawn, measured and injected without manual handling.

The Permutit Company Ltd, Permutit House, Gunnersbury Avenue, London, W4



Permutit mixed bed plants provide feed water of highest purity

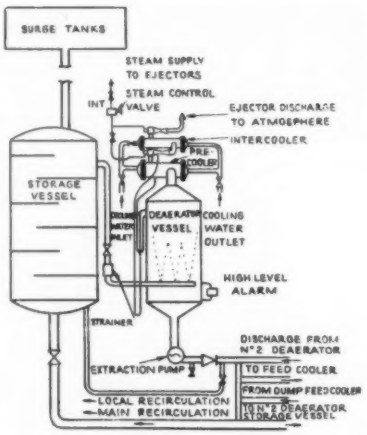
Shunt deaerators chosen to meet low oxygen requirement

Although Hick Hargreaves have made feed water deaerating equipment for many years and can claim to be one of the foremost manufacturers, the deaeration requirements for Calder represent a considerable expansion and development in this field.

The principal requirements were that the return feed temperature to the heat exchangers should not exceed 100°F and that the oxygen content of this water should not exceed ·005 cc/litre under any condition of operation. This very low oxygen content was specified to ensure that no deterioration or corrosion takes place in the relatively inaccessible reactor heat exchanger tubes.

In accordance with the specified requirements outlined above, eight sets of Hick Hargreaves cold water shunt deaerators are being installed, one set of equipment operating in conjunction with each of the eight turboalternators in the two turbine halls of the A and B stations. According to latest reports the first of these plants is operating well within the requirements of the specification.

The plant operates on the firm's well-known recirculating principle, the feed water being flashed into the deaerator through a series of spray nozzles at a vacuum corresponding to the discharge temperature of the deaerated feed water.



Percentage of deaerated water is recirculated through storage tank; ensures maximum spray efficiency

The vacuum within the deaerator vessel is maintained by a two stage ejector unit, fitted with a horizontal tubular pre-cooler and inter-cooler. Any gases liberated in the deaerator are withdrawn and discharged to atmosphere by this ejector. The operating steam of the primary ejector, together with any further vapour condensed in the tubular coolers, is returned to the system.

The deaerated water is withdrawn by an extraction pump from the base of the deaerator, and discharged to the feed coolers. As the capacity of the deaerator and extraction pump is in excess of the normal feed requirements, a percentage of the deaerated water is recirculated continuously through the storage vessel. This ensures that the deaerator sprays are always working at maximum efficiency, and further that the water entering the deaerator has, under all conditions of load and particularly at light loads, already been subject to partial deaeration, with a result that there is no falling off in the deaerator performance, even under minimum load conditions. The recirculating connection also ensures that in the event of the extraction pump being cut out, the feed pumps will not be starved.

Hick, Hargreaves & Co Ltd, Soho Ironworks, Bolton, Lancs

Parallel-slide valves from 1 in. to 28 in.

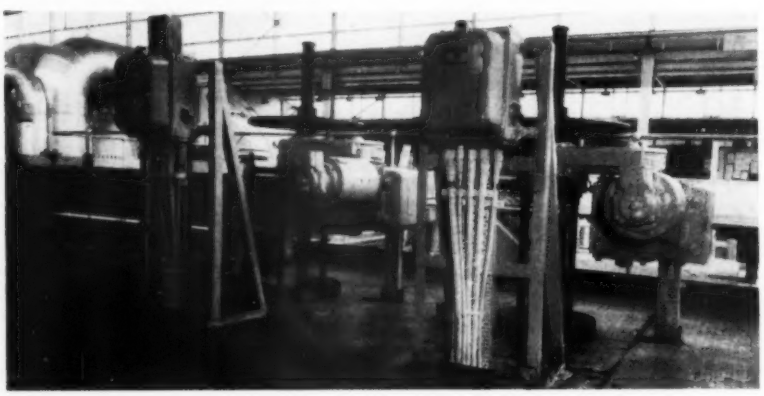
The valves and associated equipment supplied by Hopkinsons Ltd to the Calder Hall power station comprise a wide variety of items, including a large number of parallel-slide valves, ranging in size from 1 in. to 28 in. bore, some of the larger sizes being equipped with Hopkinsons' electric valve controls, complete with contactor units, push button control stations, etc.

Other large types of valves are 10 in. and 12 in. bore combined stop and isolating valves, 12 in. bore automatic exhaust valves and 20 in. bore relief valves of the deadweight type. In addition, a large number of Hopkinsons' non-return valves, *Uniflow* slide valves and *Nolos* slide valve steam traps are installed for various duties.

Specialised equipment includes desuperheating equipment with control cubicles containing both mechanically-operated 8-way spray control valves and electrically-operated 2-way spray control valves. Several centrifugal purifiers, for the continuous purification of turbine lubricating oil have also been supplied.

Hopkinsons Ltd, PO Box B27, Huddersfield, Yorks

A pair of Hopkinson 26 in. motorised valves control discharge to a dump condenser

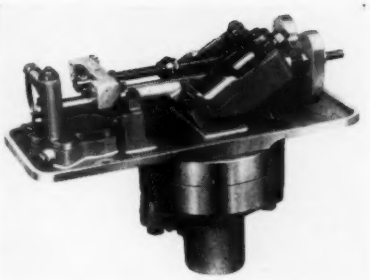


One of the valves before erection

40 *Drimacs* used for gas flow measurement

Another Elliott instrument used at Calder is the *Drimac* differential pressure transmitter of which some 40 are installed for measuring the gas flow at various points. This is a force-balance type of instrument with a wide range of applications for the measurement of liquid or gas flow, liquid level and pressure. In a differential pressure application, the pipes from the two sides of an orifice or venturi are connected to the two sides of a measuring diaphragm and a mechanical lever linkage supported on crossed-spring fulcrums transmit the force developed across the diaphragm to a nozzle-controlled air valve through which a pressure in the range of 3-15 lb/sq in. proportional to the differential pressure across the orifice plate is transmitted to the measuring or recording instrument. A balancing diaphragm is fitted to the air supply and provides feed-back to the force balance. Design features of the instrument give it an exceptionally rugged construction combined with freedom from corrosion and safety under all conditions. Drimac transmitters are available for static pressures up to 3,500 lb/sq in. and for differential pressures down to 0·5 to 3·5 inches of water.

Elliott Brothers (London) Ltd.
Century Works, London SE13



Crossed-spring pivots eliminate zero errors, give ruggedness

CALDER CONTRACTORS

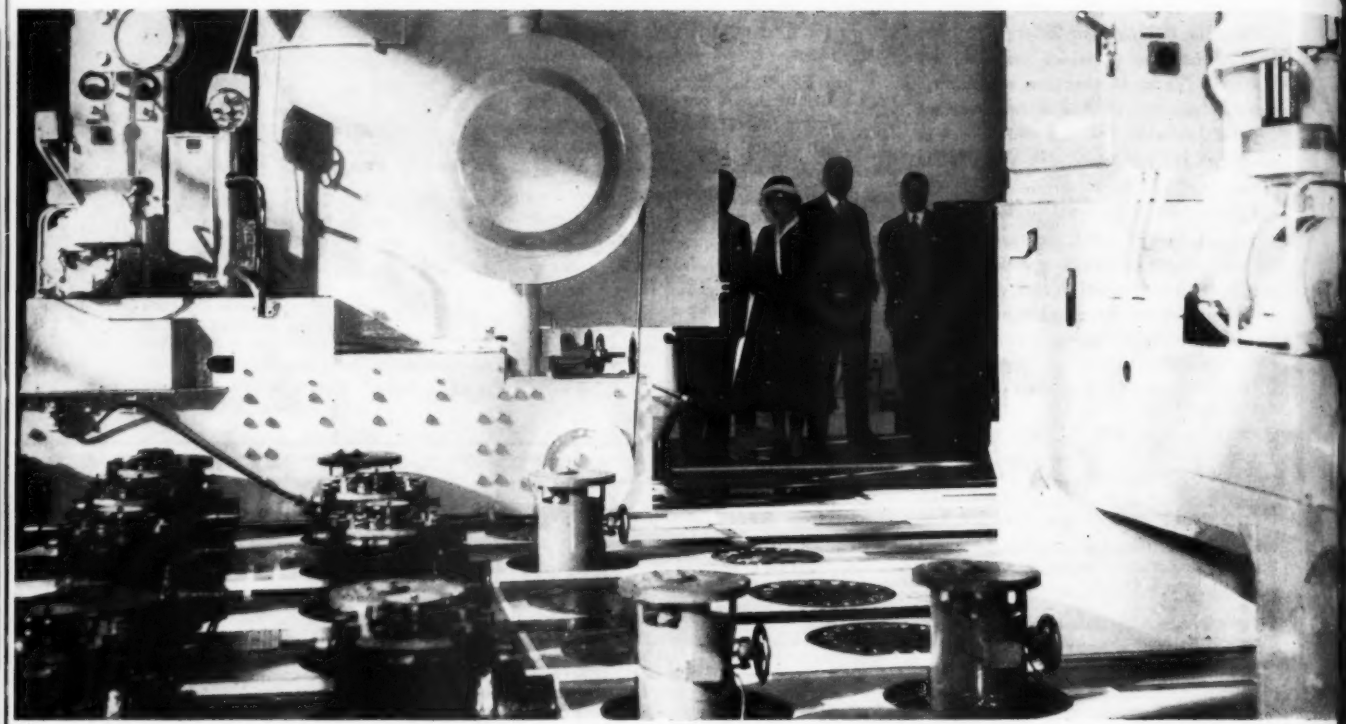
Main contractors for Calder Hall A station were

Babcock & Wilcox Ltd: heat exchangers and associated plant
Metropolitan Vickers Electrical Co Ltd: control rod actuating gear
C. A. Parsons & Co Ltd; tuboalternators; condensers, gas blowers, grid transformers
Plessey Nucleonics Ltd; burst cartridge detection gear
Strachan & Henshaw Ltd; fuel loading equipment
Taylor Woodrow Ltd: civil engineering and building
Whessoe Ltd: pressure vessels

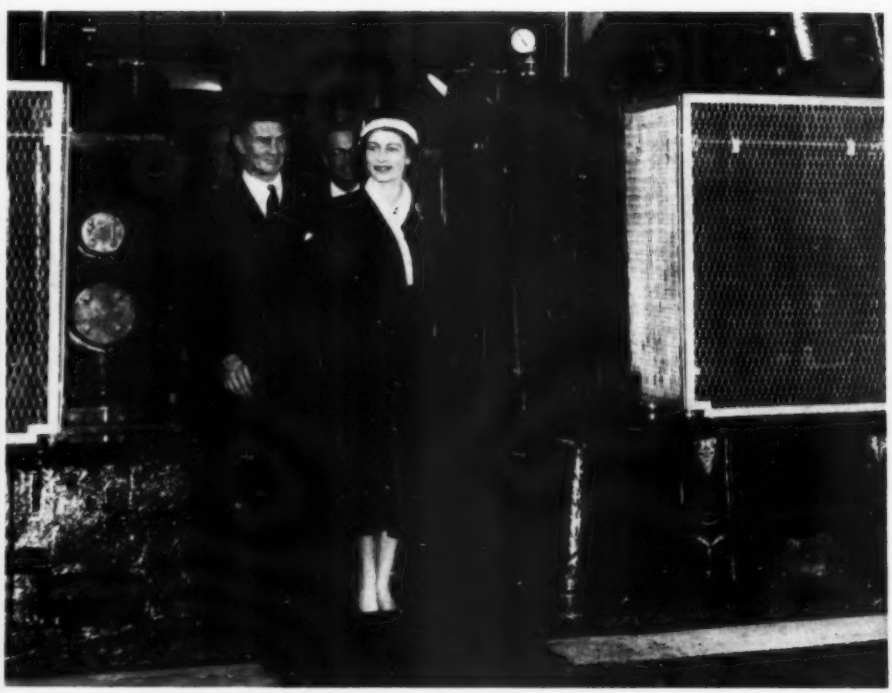
Sub contractors and suppliers included

Accles & Pollock Ltd: stainless steel tubing for burst slug plant
Accurate Recording Instrument Co Ltd: instruments
Aiton & Co Ltd: station pipework
Appleby & Ireland Ltd: vacuum and pressure gauges
N. G. Bailey & Co Ltd: lighting and electrical installation
J. Blakeborough & Sons Ltd: gas valves
Birmetals Ltd: Magnox billets for fuel cans
British Acheson Electrodes Ltd: graphite blocks
British Insulated Callender's Cables Ltd: 11kV cables, fuel hoist cables
British Thomson-Houston Co Ltd: mercury arc rectifiers
J. Brockhouse & Co Ltd: heat exchanger erection equipment
Brookhirst Switchgear Ltd; fuel loading machines electrical equipment
Bryce Electrical Construction Co Ltd: 3 and 4MVA station transformers and current limiting reactors
Burnett & Lewis Ltd: CO_2 dehumidifiers
Cable Jointers Ltd: cable work
Cambridge Instrument Co Ltd: dissolved oxygen meters, distant leading thermometers etc.
Carbon Dioxide Co Ltd: carbon dioxide plant and gas
Chatwood Safe & Engineering Co Ltd: fuel coffins
Chesterfield Tube Co Ltd: stainless steel tubing
Chloride Batteries Ltd: standby batteries
E. K. Cole Ltd: ionisation chambers and amplifiers
Colvilles Ltd: steel plate for boiler shells
Consett Iron & Steel Co Ltd: steel plate for pressure vessel
Costain-John Brown Ltd: heavy erection
Crossley Bros Ltd: diesel-driven standby generators
Darlington Insulation Co Ltd: thermal insulation
Distington Engineering Co Ltd: thermal shield exhaust stacks
Delapena & Son Ltd: induction brazing equipment
Dexion Ltd: slotted angles
Dewrance & Co Ltd: heat exchanger mountings and steam valves
Edwin Danks and Co (Oldbury) Ltd: equipment for heat exchanger erection
Electric Furnace Co Ltd: stress relieving pressure vessel
Elliott Bros (London) Ltd: 54-point chart recorders, pressure transmitters
English Electric Co Ltd: 11kV, 3.3kV and 415V switchgear
English Steel Corporation Ltd: thermal shield steel
Fairey Aviation Co Ltd: fuel can fabrication
Alexander Findlay & Co Ltd: structural steelwork
Foxboro Yoxall Ltd: chart recorders and integrators
Fluidrive Engineering Co Ltd: hydraulic couplings to gas blowers
General Electric Co Ltd: cables and other electrical components
Hadfields Ltd: special steels
Matthew Hall & Co Ltd: mechanical services
Hayward's Steel Doors Ltd: steel doors
Hayward Tyler Ltd: glandless pumps
Honeywell Brown Ltd: recorders
Hopkinsons Ltd: desuperheater controls and steam valves
James Howden & Co Ltd: i.d. fans for shield cooling
Hick, Hargreaves Ltd: deaerators
Imperial Chemical Industries Ltd: condenser tubing and plates
Isotope Developments Ltd: reactor gamma monitors
R. Jenkins & Co Ltd: coolant ductwork
Archibald Johnstone (Engineers) Ltd: heat exchanger components
George Kent Ltd: chart recorders, instruments and complete panels
The Walter Kidde Co Ltd: fire extinguishers
Lancashire Dynamo & Crypto Ltd: circulating pumps and motors
Lloyd's Register of Shipping: survey and inspection of plant
Magnesium Elektron Ltd: special alloy fabrications
Magnesium Elektron Ltd: Magnox billets for fuel cans
Marston Excelsior Ltd: gas sampling heat exchangers
Mather & Platt Ltd: Ward Leonard M/G sets, blower motor, boiler feed pumps
Measurement Ltd: flow indicators
Murex Welding Processes Ltd: arc welding electrodes
Negretti & Zambra Ltd: hygrometers
New Western (Engineering) Ltd: control room installation
Parolle Electrical Plant Co Ltd: switchboards
The Permutit Co Ltd: feedwater demineralization plant
Philips Electrical Ltd: hand and clothing monitors
Pollard Bearings Ltd: core support bearings
Pulsometer Engineering Co Ltd: pumps
Pyrotenax Ltd: mineral insulated cables
Record Electrical Ltd: instruments
A. Reyrolle & Co Ltd: 11kV switchgear
J. Rigby & Sons Ltd: heat exchanger studs
Royce Electric Furnaces Ltd: fuel magazine dryers
Shaw McInnes Ltd: 28" cast-iron pipe connectors in turbine hall
Shell-Mex & B.P. Ltd: turbine oils
Silica Gel Ltd: dehumidifiers
Steel Company of Wales Ltd: thermal shield plates
Steel Company of Scotland Ltd: thermal sleeves for heat exchangers
Stewarts & Lloyds Ltd: heat exchanger tubing
Sturtevant Engineering Ltd: dust cyclones
St George Engineers Ltd: shot-blast plant for heat exchangers
Talbot-Stead Tube Co Ltd: stainless steel tubing for burst slug plant
Tangyes Ltd: lid actuator for irradiated slug coffin
John Taylor, Dunford & Co Ltd: turbine lagging
Tilghmans Ltd: auxiliary shot-blast equipment
Vokes Genspring Ltd: constant support pipe hangers
G. & J. Weir Ltd: feed water regulators
Wharton Crane & Hoist Co Ltd: overhead cranes
Whipp & Bourne Ltd: 2 sets BTH rectifiers for feeding reactor auxiliary equipment

The Queen at Calder Hall

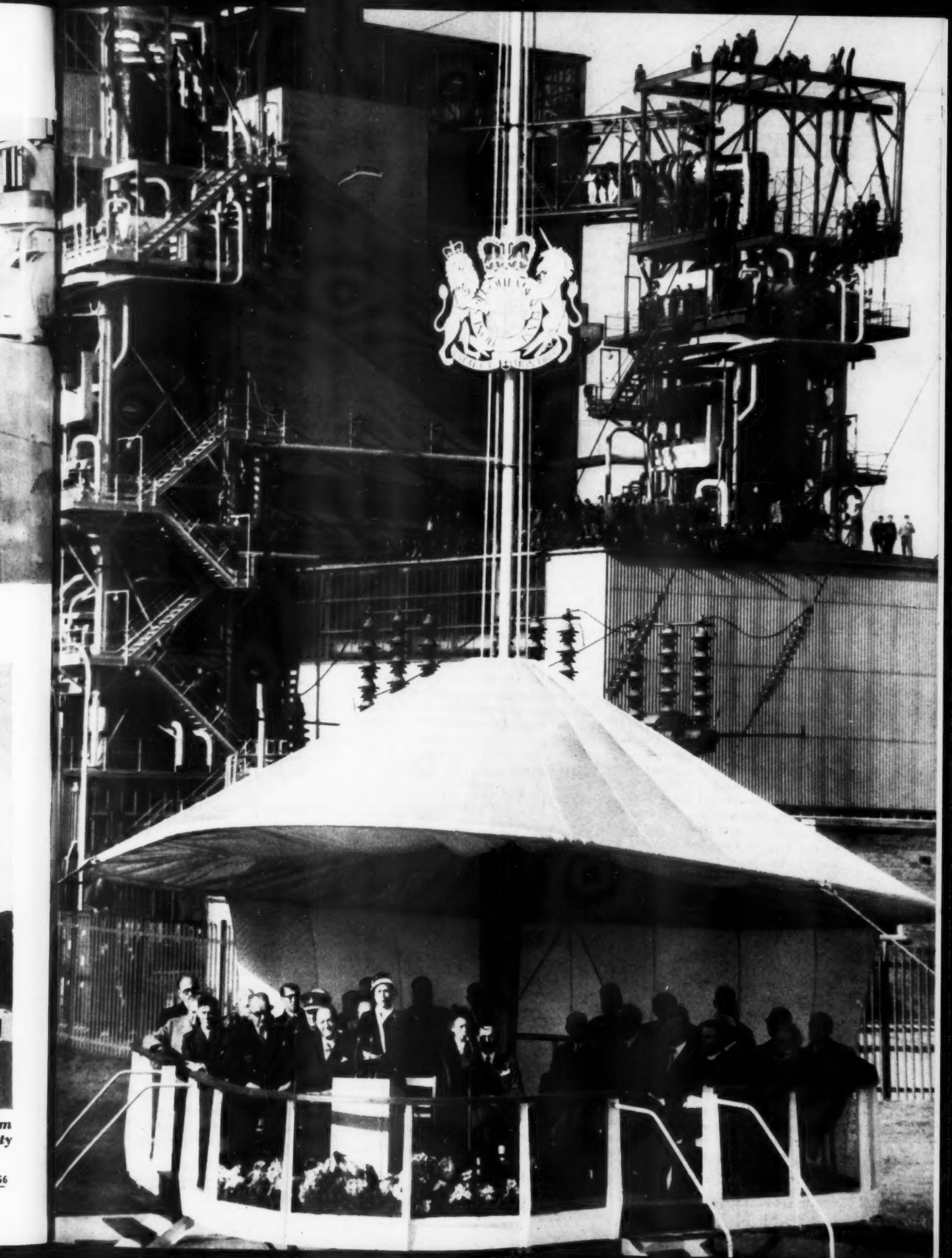


On the control and loading floor, Her Majesty accompanied by Mr R. A. Butler and Sir Edwin Plowden, views the control rod motors from behind a pair of charge machines



Works General Manager H. G. Davey shows the Queen one of the two blower houses for no 1 reactor

A point on the fuel loading system is explained to Her Majesty



WORLDVIEW

UNITED KINGDOM

GEC Turbine for Dounreay

The contract for the turboalternator to be installed at Britain's first fast-breeder reactor at Dounreay in the North of Scotland has been given by the UKAEA to The General Electric Co Ltd. The contract calls for a 15MW set to operate from 150lb/sq in, 518°F steam and to generate 3-phase 50 cycle current at 11kV. The turbine will be built at the Erith centre of the GEC/Simon-Carves Atomic Energy Group which was formed in 1954 to design and construct complete nuclear power stations. Motherwell Bridge and Engineering, who will design and construct pressure vessels for GEC-SC, are the contractors for the Dounreay containing sphere which is now almost completed.

It was also announced last month that a contract for Dounreay fuel cans had gone to Accles and Pollock Ltd—a Tube Investments company. The contract involves the production of niobium (columbium) and vanadium tubes to extremely fine tolerances. The company claim this is the first time this has been done in other than experimental quantities.

Bids received for Hunterston

Tenders for the first nuclear power station of the South of Scotland Electricity Board were received on November 1. Speaking in Inverness-shire last month at a ceremony marking the completion of the Garry hydro scheme of the North of Scotland Hydro-Electricity Board, chairman J. S. Pickles said that the station would have an installed capacity of between 250 and 300MW electric from two reactors and would cost about £35M.

The site proposed is at Hunterston, between the towns of Seamill and Fairlie on the Ayrshire coast and planning permission has been requested from the Secretary of State for Scotland, Mr James Stuart.

According to plans, no 1 reactor is due for completion in 1961, with no 2 following in 1962. It is understood that the tendering firms are the same as those which have entered bids for the first two CEA stations at Bradwell and Berkeley and that the Hunterston design will be much the same, apart from changes dictated by site considerations.

Ship talks at Harwell

British developments in nuclear ship propulsion were discussed at Harwell on Oct 19 when representatives of shipbuilding firms, shipowner's organisations and the British Shipbuilding Research Association met members of the Reactor Division under Dr J. V. Dunworth. Presiding at the conference was AERE Deputy Director, Dr B. F. J. Schonland. It is understood that both steam turbine and high temperature gas turbine systems—probably using helium—were discussed.

These talks must be viewed against the background of the American decision to go ahead with a large passenger cargo liner coupled with the US Navy's almost complete switch to nuclear power. In Europe, too, shipping interests are becoming increasingly aware of these possibilities and both Holland and Sweden have recently announced studies to bring nearer the nuclear ship.

Concern at Britain's lag in this field was expressed by Sir Donald Anderson, a deputy chairman of P & O in his presidential address to the Institute of Marine Engineers last month. Speaking for the owners, Sir Donald said they would be very glad to see the Government spending a tithe of what they spend on aviation development on work to bring nuclear shipping to the state of commercial possibility.

The Engineer's task, went on Sir Donald, was to advance engineering technique measured in terms not just of performance, but of ultimate cost. Nuclear power applied to ships was no better than any other means of raising steam, of turning a turbine rotor, unless its benefits outweigh its disadvantages when balanced in the ship's voyage account.

It is known that several British firms are cooperating in developing a nuclear submarine and that Harwell's LIDO reactor (NUCLEAR POWER October p 238) is being used to assist this project.

Steelworks run from Calder

A British steelworks is probably the first major industrial undertaking in the world to be powered entirely from nuclear generated electricity. After she had officially opened Calder Hall on October 17, The Queen drove to nearby Workington where, in a ceremony at the Workington Iron and Steel Company, she operated a switch which brought power into the works from Calder Hall. Input was enough to run the whole plant from nuclear power. Much of the power is used in the rolling mills which are making rails for export. The ceremony and tour of the works was seen by hundreds through closed circuit television networks supported by Marconi's. Part of the vision circuit was carried by a super high frequency radio link.

Cut X-rays—ICRP Chief

In a world using nuclear energy for power, we are faced with the problem of disposing of "enormous quantities of highly dangerous radioactive waste" so that no harm will come to anyone. This is a very serious problem but one that can be dealt with and solved, according to Sir Ernest Rock Carling, Chairman of the International Commission on Radiological Protection speaking in London last month.

Sir Ernest was addressing an audience of nurses and he said that the background dose received by the human race had increased by 25 per cent in the last 50 years. Much the greater part of this, he went on, came from diagnostic radiology and it had become clear that all sources of radiation had to be limited to the barest minimum. Sooner or later, said Sir Ernest, there would have to be a "cease-fire" for bomb tests: a world atomic war would be a lethal catastrophe for all peoples.

FRANCE

Europe's need for 235 and D_2O

During the period 1960-5 the OEEC countries (excluding the UK) might need from 7,000 to 15,000 kg of 'additional' U-235 in the form of slightly enriched uranium (up to 3 per cent) according to the Organisation's 'Joint Action in the field of nuclear energy' published in Paris last month. The corresponding figure for highly enriched uranium will probably lie between 2,000 and 6,000 kg. The report considers that during this period, U-233 will only be available in very small quantities and so will Pu-239. Furthermore, until plutonium technology has been more developed, its use in reactors is bound to be restricted. It therefore believes that Europe urgently needs a diffusion plant for the enrichment of uranium for use in power reactors. The plant visualised might handle up to 500 tons of natural uranium a year and increase the enrichment up to 1·5 per cent. Highly enriched fuel, too, however, would have to be produced. As a natural consequence of this, a chemical processing plant would also have to be built and this too would handle the 500 tons.

On heavy water, the OEEC working committee are strongly of the opinion that production plans should be made since they consider that, even at its present high cost, D_2O can compete with any other moderator. It was unable to make any firm estimate of demand, but assuming a gross installed nuclear capacity in the member countries (excluding UK) of 12,500MW (heat) in 1965 and 38,500MW (heat) in 1970 it estimates that if one third of this were supplied from D_2O-moderated reactors the demand would be 500-1,000 tons in 1965 and 2,000 to 4,000 in 1970. An annual pro-

duction of roughly 400 to 450 tons might therefore be necessary. At present, the total annual output within the Organisation is 12 tons (all from Norway).

If D_2O can be made economically as a byproduct, OEEC consider that Europe's requirements could largely be met by private industry in plants set up as ancillaries to ammonia synthesis and other works. If, however, production were not sufficient or if it were preferable on technical or economic grounds, primary D_2O plants would be needed and these would probably be joint undertakings.

SOVIET UNION

JINR opened

The nuclear research facilities of the Academy of Sciences at Dubna, some 95 miles from Moscow on the Volga, were handed over on September 28 to the newly-formed Joint Institute of Nuclear Research (NUCLEAR POWER, August, p 154). Speaking to correspondents, director Dmitri Blokhintsev said that the laboratories would be devoted entirely to peaceful research and that all its work would be non-secret and published. Professor Blokhintsev said that scientists from non-member countries would be welcome to visit and work at the Institute. JINR's budget for 1956-7 is 230M roubles (£20M). Former Harwell scientist Bruno Pontecorvo is in charge of a section of the laboratories at Dubna.

200MW reactor model

A permanent All-Union Industrial Exhibition demonstrating the latest achievements of Soviet engineering is now open in Moscow. One of its pavilions is devoted to atomic energy and a model of the 5000kW nuclear power station of the USSR Academy of Sciences is included.

The exhibition also illustrates the design of a 200MW enriched-uranium, light-water-moderated reactor. The core is contained in a cylindrical vessel with spherical ends and comprises both natural and enriched uranium bars. The output is regulated by moving the fuel rods and introducing absorbing rods. Water at 100 atmospheres is heated in the reactor to 270°C and heat exchangers raise dry steam at 32 atmospheres and 235°C for the turbine.

UNITED STATES

UN studies radiation

The committee set up by the UN General Assembly last year to study the effects of radiation on man and his environment began a two-week session in New York on October 22. Under chairman Charles Chagas (Brazil) and vice-chairman Zenon Bacq (Belgium) the 15-nation committee agreed to discuss genetic effects, ocean disposal of waste, biological effects of small doses.

To aid its work, it has before it 34 reports from 22 governments and as a matter of high priority the committee is to consider data received on strontium-90 build up in milk and fish as a result of bomb fall out.

10MW reactor for Alaska

A nuclear power plant is to be built at Anchorage, Alaska, by the Chugach Electric Association and the Nuclear Development Corporation of America, White Plains, NY. AEC approval for initial design and development work was obtained for this on August 27 under the Power Demonstration Programme. Considerable AEC financial assistance will be called for.

The reactor will be of 10MW electric capacity and heavy-water-moderated, sodium-cooled. Only a low enrichment of U235 will be needed and since power is already very costly in Alaska, the nuclear plant should be competitive much sooner than in the metropolitan United States. The AEC announcement added that although extensive technical knowledge exists on heavy water and sodium separately, a 'significant amount' of research would be needed to develop technology using both together.

Ship reactor non-secret

America's first nuclear-powered merchant ship will not be secret and the reactor design will be on an unclassified basis so that engineers from all nations will be able to benefit. It will, in fact, be a floating research laboratory. This was stated by President Eisenhower in Washington on October 15 in the course of a directive to the AEC and the Department of Commerce to proceed with the vessel "as rapidly as possible." Mr Eisenhower said it was a project in which he had a deep interest and recalled that he advanced the idea of the nuclear ship in April 1955. In a joint reply to the President, Secretary of Commerce Weeks and AEC Chairman Strauss reported that joint Maritime Administration/AEC talks had agreed that the vessel would have a 20,000 h.p. pressurized water reactor of "advanced design" and that it would carry 100 passengers and 12,000 tons of cargo. It would have a service speed of 21 knots and measure 595 ft long, 78 ft beam and would draw 30 ft of water.

Delivery of the ship will depend on how long it takes to complete the power plant and this is currently estimated at 39 months from the contract signing. To carry out the President's wishes the entire project will be under the control of one man to be chosen jointly by the Maritime Administration and the AEC.

A warning that nuclear shipping would not be without its dangers was voiced on September 20 by Dr Richard Fayram of Aerojet-General Nucleonics, San Ramon, Cal. Speaking at the University of California Dr Fayram pointed out that in a collision or a sinking, biological shields were liable to be broken thus allowing an escape of radioactivity. Since an average of seven large ships could be expected to sink each year, this would constitute a serious hazard. Of the seven, two could be expected to sink on the high seas and would do relatively little harm, but the remainder would sink in coastal waters or even in harbour and this would be very dangerous.

'Atoms for Peace' statute signed

The International Atomic Energy Agency came into being—on paper at least—in New York on October 26 when the statute was signed in New York by the delegates to the 82-nation conference which approved it. Before it can take full effect, however, the statute has to be ratified by the individual governments. Vienna was accepted as the headquarters of the Agency and now an 18-nation preparatory commission has the task of physically giving it substance. It is expected that the IAEA will be operating towards the end of 1957.

During the New York discussions the draft statute was modified in certain respects, but in the main it has retained its original intentions. The main compromise arrived at is in Article 12 which deals with the control of fissionable materials. It now has the effect that Agency inspectors will be able to visit recipient countries to ensure that fuels are not used for military purposes. Moreover, byproducts must now also be applied only for peaceful uses or returned to the Agency pool.

The Agency represents a great personal triumph for President Eisenhower whose famous 'atoms for peace' message to the UN in December 1953 was the starting point for this outstanding achievement in international cooperation. Reports from New York also speak highly of the skill of Sr. Muniz of Brazil who presided at the conference.

At the signing, a message from Mr Eisenhower was read by AEC's Lewis L. Strauss. This said the United States would make available to the Agency, 5000 kg of U-235 from the 20,000 kg set aside last February for peaceful uses by friendly nations. In addition, the US intends to supply as much nuclear material as all the other countries combined in the period between the IAEA's setting up and July 1st 1960. The President concluded with a warning that the benefits of nuclear power 'may come to us more slowly than we could wish.'

COMPANIES

Cable irradiation at BICC

To investigate properties of irradiated dielectric materials, the Research Organization of British Insulated Callender's Cables Limited have for several months been operating a 2MV Van de Graaff accelerator at their Wood Lane laboratories, London. This equipment was chosen because it can provide a source of electrons, positive ions, gamma rays and neutrons.

The high energy radiation is being used to modify the structure and properties of conventional polythenes and an exhaustive programme of study of the physical and electrical properties of such materials after irradiation, has been started, with special emphasis on their uses as cable insulants.

The irradiation laboratory comprises a central generator block of two storeys, with the target room on the ground floor immediately under the generator room, flanked on each side by cable handling and control laboratories. The concrete walls of the target room are 3 feet thick to prevent the radiation in the laboratories from rising above the tolerance level, while those of the generator room in which the radiation intensity is lower, are 2 feet thick.

Cable under radiation traverses the target room through two slits in the concrete walls, and is handled by conventional take-up and haul-off cable machinery.

The leakage of dangerous amounts of X-radiation and of electrons into the laboratories is prevented by covering the slits on the outside with 6 inches of lead bricks and on the inside with rubber snuggers and aluminium doors.

The electron beam from the accelerator tube in the generator is scanned electromagnetically so that it emerges from the aluminium window of the scanning bucket as a beam having its longer axis parallel to that of the cable.

With these arrangements it has been found possible to process continuously polythene insulated cables. First investigations into the properties of such cables, after irradiation, have indicated that amongst other advantages, a substantially raised softening temperature results. The plant is the first in Great Britain to process plastic insulated cables in this way, and will greatly assist in the assessment of irradiated materials for general use in the cable industry.

The equipment was supplied by the High Voltage Corporation of Cambridge, Mass, and is similar to that installed at the TI Laboratories, Hinxton Hall (NP May 1956).

B-10 produced commercially

Claimed to be the first commercial isotope separation plant in the world, a boron 10 column is now in full production at 20th Century Electronics Ltd, New Addington, Surrey. Construction of the plant was completed in the comparatively short time of eight months and the programme was so urgent that the 30 ft high column was actually constructed long before the building which was to accomodate it.

The column, a narrow tube intricately packed with 5 miles of stainless steel wire, is suspended centrally in a metal vacuum vessel in order to avoid heat losses. It weighs, together with control equipment, several tons and cost in the region of £2,000 per foot. The raw material is distilled at the base and the product is then passed through the column, which is set at various extremely accurate temperatures throughout its length, until it condenses as a colourless liquid. This is taken off at the rate of a droplet every few minutes, the total output being about a pint a month. In further involved chemical processes the liquid is purified and stored in glass containers in the form of boron-trifluoride etherate.

The product is used chiefly for filling 20th Century's boron-trifluoride neutron counters (NP May 1956 p 41), but it also has important other uses, not only in nuclear research, but also in medicine.

The construction and operation of the B-10 column is under the supervision of ex-Harwell scientist, Alan Edmunds, and it is based on a UKAEA design developed by R. McIlroy. Although the productive processes use up-to-date methods of automation, it is still necessary to maintain constant inspection day and night. The column works continuously and every possible precaution is taken to ensure constant and uniform conditions. Should there be any interruption of the process it might take a month or longer to restore the conditions of equilibrium vital to successful production.

The B-10 produced has an enrichment of over 99 per cent, which is better than had been expected. The Russians showed an experimental column at Geneva but their product had an enrichment of only 87 per cent. A valuable by-product of the British column is boron 11 — of great value in nuclear research.

At present the total production of B-10 is barely sufficient to meet the needs of Harwell, but the firm plan the construction of several other columns of greater heights. The atomic energy authorities of several foreign countries have already expressed interest in the establishment of duplicate plants and 20th Century, which has in the past sold important licences to prominent European countries, is discussing with government authorities to what extent British 'know-how' can be exported.

The new Babcock House

The new London head office of Babcock & Wilcox, Limited, in Euston Road, was formally opened on October 8, when managing director Sir Kenneth Hague unveiled a bronze plaque in the main entrance hall, in the presence of chairman W. Lionel Fraser and directors of the company, together with guests representing those responsible for the building's construction.

The 8-storey building will accommodate some 1500 members of the London staff, and will replace the present Babcock House in Farringdon Street, as well as Greenly House and Audrey House in Houndsditch, and other smaller offices in the City.

The building is equipped with the most modern facilities for the comfort of the staff Central heating by an embedded floor pipe system is provided throughout the building by two *Steambloc* automatic, oil-fired packaged boilers supplied by a Babcock subsidiary company. Among other features of interest are a 48-seat cinema, for the showing of technical films and slides, an exhibition room for the display of models and exhibits illustrating the company's many activities and a special purpose technical library to maintain an up-to-date service of periodicals and publications relevant to the company's interests in all fields of industry.

A Ferranti Pegasus electronic digital computer will be installed in 1957. The machine with its team of operators will provide a mathematical and scientific service for many departments. Programmes have already begun on boiler heat transfer, pressure losses and circulation. The computer will also be used to analyse piping stresses, steel structures and to solve nuclear engineering problems.

In the entrance foyer the history of steam, and the benefits its power has brought to mankind in industrial and marine usage all over the world, is symbolically illustrated in two large murals by Eric Fraser, the central motif being a striking representation of Calder Hall atomic power station.

Babcock's first London office was set up in Newgate Street nearly 70 years ago, the staff consisting of three men and an office boy.

INSTITUTIONS

Measuring reactor power

The measurement of radioactivity formed the subject of his address when Dr Denis Taylor, Head of Electronics Division, Harwell, was installed as the new chairman of the Measurement and Control Section of the Institution of Electrical Engineers in London on October 9. Dr Taylor commenced with an introduction to the geometry and sensitivity of counting systems with particular reference to the background rate. He then went on to discuss methods of measuring body radioactivity. In particular, he described the AERE apparatus which uses four photo-multiplier tubes with sodium iodide scintillators. This registers the normal body burden of K-40 to plus or minus 3 per cent in a 10 minute count, or plus or minus 1 per cent in a 90 minute count.

The Chairman had something to say about the measurement of fission rate in reactors and described how, in order to cover the whole range of output from shut-down to full power in British reactors two distinct systems are used (1) an ion chamber in association with a d.c. amplifier for high power levels, and (2) a pulse counter, either a fission chamber or a BF_3 proportional counter, in association with a counting rate meter for low levels and start up. He remarked that in high fluxes, B-10 counters suffered from rapid boron depletion and that lithium-6 or possibly uranium-235 could provide a longer-lived detector. Dr Taylor is Instrumentation Editor of NUCLEAR POWER.

NAMES IN THE NEWS

Mr Andrew Young, *UKAEA Resident Engineer at Calder Hall, is to leave the Authority shortly to join C. A. Parsons & Co Ltd, Newcastle on Tyne.*

Mr F. W. Martin *has joined the board of Tube Investments Ltd.*

Mr W. A. Harton, *Works Director of George Kent Ltd, is on a visit to Canada to review progress of Kent Noratlantic who now manufacture Kent equipment in the Dominion.*

William G. Friedrich *has been made director of international relations of Vitro Corporation of America. Dr Friedrich will assist Vitro's activities in atomic energy research and development, one of which is a survey for the government of India of a heavy water/nitrogen fertiliser project in the Bhakra-Nangal area.*

Dr Park H. Miller Jr *has joined the General Atomic Division of General Dynamics Corporation. Dr Miller was previously professor of physics at the University of Pennsylvania and has specialised in solid-state and surface physics.*

Mr P. W. Mummery, *AERE, Harwell, has been elected as Fellow of the Institute of Physics.*

Major-General C. A. L. Dunphie, *CB, CBE, DSO, a director of Vickers Ltd, has been appointed Managing Director.*

Mr H. E. Vickers, *Generation Engineer (Ops), Yorkshire Division of the CEA has been appointed Chief Generation Engineer (Ops), South Western Division.*

Mr C. M. Houlton, *General Sales Manager of Borax Consolidated Ltd is on a visit to the Far East.*

PROGRAMME

November

Thu 1 **Glasgow** IMechE *Nuclear pressurised water reactors* J. M. Kay and F. J. Hutchinson. 7.30 at Technical College

Fri 2 **Fawley** SIT *Mass spectrometers* J. Blears. 7.00 at Copthorne House
Aberdeen IMechE *Repeat of Kay and Hutchinson paper of 1 Nov.* 7.30 at Robert Gordons College

Mon 5 **Newcastle** ICE, IEE, IMechE *Nuclear reactors for power generation* B. L. Goodlet. 6.15 at Lit and Phil Society
London IPE *Radioisotopes in industry* C. W. Jones. 7.00 at Royal Society of Arts
London SCI *Recovery of uranium from low-grade ores* T. V. Arden. 6.30 at 14, Belgrave Square

Tue 6 **Manchester** IEE *Conduction and induction pumps for liquid metals* L. R. Blake. 6.15 at Engineers Club, Albert Square
London IEE *Electric strength of highly compressed gases* E. H. Holt. *Insulation properties of compressed electro-negative gases* P. R. Howard. 5.30 at the Institution
Oxford IM *Radiation damage* A. T. Churchman. 7.00 at Cadena Cafe, Cornmarket Street

Thu 8 **London** IEE *Visit of British delegation to USSR* J. Eccles. 5.30 at the Institution
Glasgow IPE *Introduction to atomic energy* J. A. Dixon. 7.15 at Scottish Building Centre, Sauchiehall Street

Mon 12 **Ipswich** IEE *Atomic power stations* D. F. Welch. 6.00 at Crown and Anchor
Newcastle IEE *Control and instrumentation of a nuclear reactor* A. B. Gillespie. 6.15 at Neville Hotel

Wed 14 **Birmingham** IChemE *The handling of sulphuric, nitric and hydrochloric acids* H. Saenger. 6.30 at Birmingham and Midlands Institute, Paradise Street
Sheffield SIT '*Pneutronics*' R. B. Smith. 7.00 at the University

Thu 15 **Dublin** IEE *Swimming pool reactors* Prof. T. E. Nevin. 6.00 at Trinity College
Liverpool IM *Some metallurgical aspects of welding non-ferrous metals* P. T. Houldcroft. 7.00 at 9 The Temple, Dale Street

Tue 20 **London** IEE *Data processing for experimental work* Discussion opened by M. V. Wilkes. 5.30 at the Institution
Manchester SIT *Control of distillation columns* J. W. Broadhurst. 7.30 at College of Technology

Wed 21 **Leeds** IChemE *Non-Newtonian fluids* E. G. Richardson. 7.00 at the University
Chester SIT *Instrumentation and the chemical flowsheet* J. S. Hunter. 7.00 at 5 Kings Buildings, King Street
Middlesbrough SIT *Data reduction* C.A.Laws. 7.30 at Cleveland Institution
Manchester IM *The role of grain boundaries in creep* D. McLean DSc. 6.30 at the Central Library

Thu 22 and Fri 23 **London** BNEC *Calder Hall Symposium* 10 a.m. each day. Central Hall, Westminster. Admission by ticket only—from BNEC Secretary, 1-7 Gt George Street SW1

Tue 27 **Swansea** IEE *Nuclear energy in the service of man* Dr T. E. Allibone. 6.30 at Brangwyn Hall
Cardiff IPE *Inert gas welding processes* Mr Woolcott. 7.15 at S.W. Engineers' Institute, Park Place

Thu 29 **Bristol** IEE *Nuclear energy in the service of man* Dr T. E. Allibone. 6.30 at Colston Hall
Chelmsford IMechE *Application of atomic energy to power production* S. C. Curran. 7.30 at Hoffman Hall

Fri 30 **London** PS *Discovery of V-particles and the properties of hyperons* Prof G. D. Rochester and Dr C. C. Butler. 5.00 at Science Museum
London IMechE *American system of education and training of mechanical engineers* H. S. Arms. *Education of engineers in Europe* Prof S. J. Davies. 6.00 at Institution

December

Mon 3 **London** IEE *Nucleonic devices in automation*—informal talk by Denis Taylor. 5.30 at the Institution
London SChemE *Elementary particles of nature* Prof P. M. S. Blackett. 6.30 at 14 Belgrave Square SW1

Tue 4 **Chester** IChemE *Centrifugation as a unit operation.* 7.15 at Birkenhead Technical College

Wed 5 **Manchester** IEE *Junction and point-contact transistor scaling circuits* G. B. B. Chaplin and A. R. Owens. 6.45 at Engineers Club
Manchester IM *Boron in Steel* F. B. Pickering. 6.30 at the Central Library

Thu 6 **London** IM *The founding of magnesium* E. F. Emley. 6.30 at 16 Belgrave Square SW1

FACTORS GOVERNING neutron multiplication in a homogeneous medium are discussed and the variations in the number of fission neutrons produced per neutron absorbed in the fuel with the fraction of U-235 in the fuel are found. The resonance escape probability and thermal utilisation are found to depend on the amount of moderator present. A homogeneous mixture of graphite and moderator is used to illustrate the effect on the multiplication constant by increasing the uranium enrichment. The equations for the spatial distribution of slowing-down and diffusing neutrons in an infinite multiplying medium are derived. This introduces the quantity known as "buckling" which is a function of the multiplication constant and the slowing-down and diffusion lengths in the medium.

ON DISCUTE LES FACTEURS régissant la multiplication des neutrons dans un milieu homogène et l'on détermine la manière d'après laquelle les variations du nombre des neutrons de fission, relatif à un neutron absorbé par le combustible, dépendent du contenu de U-235 dans le combustible. On trouve que la probabilité d'échapper à la capture par résonance et l'utilisation thermique dépendent de la quantité actuelle du modérateur. On emploie un mélange homogène du graphite et du modérateur pour illustrer l'effet sur la constante de multiplication, en augmentant le degré d'enrichissement de l'uranium. On développe les équations pour la distribution spatiale des neutrons de ralentissement et de diffusion dans un milieu infini de multiplication. Ces équations contiennent une quantité dite le Laplacien du réacteur ("buckling"), qui est une fonction de la constante de multiplication et des parcours de ralentissement et de diffusion dans le milieu.

DIE FÜR NEUTRONENVERMEHRUNG in einem homogenen Medium massgebenden Faktoren werden erörtert; man findet gleichfalls, auf welche Weise die Veränderung der Spaltungsneutronenanzahl je ein im Brennstoff absorbiertes Neutron vom Brennstoffgehalt an U-235 abhängt. Man findet, dass der Resonanzfluchtfaktor und die thermische Nutzung von der vorhandenen Moderatormenge abhängen. Man verwendet ein homogenes Graphit-Moderator-Gemisch, um den Einfluss auf die Vermehrungskonstante durch Steigerung der Uraniumanreicherung zu veranschaulichen. Es werden Gleichungen für die räumliche Verteilung der Verlangsamungs - und Diffusionsneutronen abgeleitet. Hierdurch wird eine als Flusswölbung ("buckling") bekannte Grösse eingeführt, die eine Funktion der Vermehrungskonstante sowie der Verlangsamungs- und Diffusionslänge darstellt.

EN ESTE ARTICULO SON DISCUTIDOS los factores que rigen la multiplicación de neutrones en un medio homogéneo y se descubren las variaciones en el número de neutrones de fisión producidos por cada neutron absorbido por el combustible con la fracción de U-235 en el mismo. Se comprueba que la probabilidad de escape por resonancia y la utilización térmica dependen de la cantidad presente de moderador. Una mezcla homogénea de grafito y moderador es usada para demostrar el efecto en la constante de multiplicación mediante el aumento del enriquecimiento del uranio. Se deriva las equaciones para la distribución espacial de neutrones difusores y retardadores en un medio de multiplicación infinito. Esto introduce el factor "buckling" que es una función de la constante de multiplicación y de los trayectos de retardación y difusión en el medio.

ОБСУЖДАЮТСЯ ФАКТОРЫ, управляющие размножением нейтронов в гомогенной среде, а также определяется зависимость изменения числа нейтронов деления, получаемых вследствие поглощения топливом одного нейтрона, от содержания U-235 в топливе. Оказывается, что вероятность избежания резонансного захвата и использования тепловых нейтронов зависят от имеющегося количества модератора. Гомогенная смесь графита с модератором употребляется для того, чтобы, путем увеличения степени обогащения урана, об'яснить влияние на коэффициент размножения. Выводятся уравнения для пространственного распределения нейтронов замедления и диффузии. Этим вводится величина, известная под названием кривизны (лапласиана) и являющаяся функцией коэффициента размножения, длины замедления и диффузионной длины.

Reactor Physics-6

I. The value of k for a homogeneous system

(1) The fast fission effect ε

In general, it can be said that ε will be unity in a homogeneous system. This is because the fissionable material will be so dispersed in the moderator that a fission neutron will almost certainly be slowed down by the moderator before it has a chance to make a fast fission.

(2) The thermal fission factor η

The calculation of η is in fact independent of whether the system is homogeneous or heterogeneous for as can be seen from (5.30) it depends only on cross-sections and amounts of material present.

It is convenient to rewrite η. As defined in (5.30) it refers to uranium containing any fraction of U^{235}. The fraction of U^{235} present in any sample of uranium may be defined in terms of the enrichment factor E by

$$E = \frac{\text{fraction of } U^{235} \text{ atoms in enriched uranium}}{\text{fraction of } U^{235} \text{ atoms in natural uranium}} \qquad (6.1)$$

where "enriched uranium" simply means uranium in which the U^{235} content is different from that in natural uranium. Then from (6.1) $E = 1$ is natural uranium and $E = 139$ is pure U^{235}.

Using (6.1) and (5.34) in (5.30) then gives

$$\eta = \frac{\eta(25)}{1 + \dfrac{139 - E}{E} \cdot \dfrac{\sigma_a(28)}{\sigma_a(25)}} \qquad (6.2)$$

The important thing to note about η as a function of E is that it increases rapidly with E at first and then only very slowly after about $E = 10$. (See table 6.2).

The definition of η can be extended to apply to any mixture of fissionable and non-fissionable materials forming the fuel, then

$$\eta = \sum_i \eta(i)\, N(i)\, \sigma_a(i) \Big/ \sum_i N(i) \sigma_a(i) \qquad (6.3)$$

where $\sum_i$ represents summation of the different materials i and $\eta(i)$ is zero for non-fissionable materials.

(3) The resonance escape probability p.

This has been shown above to be given by (5.11), where Σ_a was assumed independent of the energy E. Now suppose also that the fuel used is uranium and that the absorption in the resonance region of materials other than U^{238} can be neglected. Then Σ_a can be written as

$$\Sigma_a = N(28)\, \sigma_a(28) \qquad (6.4)$$

where $\sigma_a(28)$ is still energy-dependent. Substituting (6.4)

by James F. Hill Senior Lecturer, Reactor School, Harwell

NUCLEAR POWER'S course in basic theory this month deals with neutron multiplication in a homogeneous reactor and introduces the idea of "buckling"

into (5.11) leads to

$$p = \exp\left[-\frac{N(28)}{\xi \Sigma_s} \int_{E_{th}}^{E_o} \sigma_a(28) \frac{\Sigma_s}{\Sigma_s + N(28)\sigma_a(28)} \cdot \frac{dE}{E} \right] \tag{6.5}$$

The integral is called the effective resonance integral and written

$$\int_{E_{th}}^{E_o} \sigma_{eff} \frac{dE}{E} \tag{6.6}$$

with

$$\sigma_{eff} = \frac{\sigma_a(28)\,\Sigma_s}{\Sigma_s + N(28)\,\sigma_a(28)} \tag{6.7}$$

so that p can be written

$$p = \exp\left[-\frac{N(28)}{\xi \Sigma_s} \int_{E_{th}}^{E_o} \sigma_{eff} \frac{dE}{E} \right] \tag{6.8}$$

Now from (6.7) and (6.8) it can be seen that σ_{eff} and p are both functions of the quantity $\Sigma_s/N(28)$. This quantity is the scattering cross-section of the mixture per atom of resonance absorber.

There are two interesting limits to the value of the effective resonance integral (6.6). Consider first the case when the ratio of moderator to uranium is increased. This means $\Sigma_s/N(28)$ increases and in the limit as the uranium becomes infinitely dilute $\Sigma_s/N(28) \to \infty$, and so from (6.7)

$$\int_{E_{th}}^{E_o} \sigma_{eff} \frac{dE}{E} \longrightarrow \int_{E_{th}}^{E_o} \sigma_a(28) \frac{dE}{E} \tag{6.9}$$

and the value of this integral is found experimentally to be 10·2 barns.* In this case, of course, $p = 1$, which is verified by putting $\Sigma_s/N(28) = \infty$ (6.5), and so p is independent of the value of the effective resonance integral.

In the other case in which the ratio of moderator to uranium in decreases until ultimately pure uranium is reached $\Sigma_s/N(28)$ has the value for natural uranium namely 8·3 barns and experimentally it is found that

$$\int_{E_{th}}^{E_o} \sigma_{eff} \frac{dE}{E} \simeq 290_{\text{ barns}} * \tag{6.10}$$

In this case p is almost equal to zero because the fission neutrons can only be slowed down by uranium. In doing so they only lose on average a small fraction of their energy at each collision and so will have a very small chance of avoiding resonance capture.

The value of the effective resonance integral has been measured for different values of $\Sigma_s/N(28)$ and its value appears to be independent of the scattering material with which the uranium is mixed. Typical values of the integral taken from the article by Macklin and Pomerance are quoted in table 6.1 where all the cross-section are in barns.

$\Sigma_s/N(28)$	$\int_{E_{th}}^{E_o} \sigma_{eff} \frac{dE}{E}$
8·3	10·2
50	19
100	27
300	45
500	56
800	68
1000	75
2000	98
∞	290

Table 6.1 *effective resonance integral for* U^{238}

(4) The thermal utilisation *f*.

As the system is homogeneous the relative thermal absorptions of the different components will be simply proportional to the respective cross-sections. So f will be given from (5.28) by

$$f = \frac{N(U)\,\sigma_a(U)\,V(U)}{N(U)\,\sigma_a(U)\,V(U) + \sum_i N(i)\,\sigma_a(i)\,V(i)} \tag{6.11}$$

where $N(i)$ is the number of atoms of material i per cm^3 of material i, $V(i)$ the total volume of material i in the system and the summation is over all the materials in the system except uranium. In the special case in which only uranium and moderator (M) are present (6.11) becomes

$$f = \frac{N(U)\,\sigma_a(U)\,V(U)}{N(U)\,\sigma_a(U)\,V(U) + N(M)\,\sigma_a(M)\,V(M)} \tag{6.12}$$

It was seen in the last paragraph that p was large for large values of moderator to uranium atoms. However, from (6.12) the reverse applies in the case of f, for f decreases as the proportion of thermal neutrons absorbed by the moderator increases.

(5) The value of *k* in the infinite system

Consider the simple case of a mixture of uranium and moderator and the value of the product pf for such a system. It is clear from the arguments above that pf will have a maximum value for some definite ratio of moderator to uranium atoms as p increases and f decreases as this ratio increases. And as ε has been taken to be unity and η is a constant depending only on the type

* See *Resonance Capture Integrals* by R. L. Macklin and H. S. Pomerance in Progress in Nuclear Energy Series I, Vol. I Pergamon Press 1956

of uranium used then for a particular enrichment of uranium the maximum value of k will be given by the maximum value of pf.

It is instructive to consider the possibility of a self-sustaining chain reaction in a homogeneous mixture of natural uranium and graphite. From the effective resonance integral in table 6.1 and (6.12) above p and f can be found and it can be shown* that the maximum value of pf occurs at a ratio of graphite to uranium atoms of about 300 with $p = 0{\cdot}70$, $f = 0{\cdot}84$, $pf = 0{\cdot}59$ and $k = 0{\cdot}78$. This then is the maximum value of k attainable in a homogeneous mixture of natural uranium and graphite and so, as this is less than unity, a self-sustaining chain reaction is impossible with such a mixture.

If we wish to make such a reaction possible the value of k must somehow be increased to greater than unity. This can be achieved by removing some of the U^{238} which absorbs neutrons wastefully, or in other words increase the fraction of U^{235} in the uranium. It can also be assumed for small values of E that the value of p will be substantially unaltered. (For $E = 2$ the ratio of U^{238}, which determines the value of p, in the enriched uranium to that in natural uranium is 137/138.)

The effect of enrichment then will be to increase the absorption cross-section per uranium atom. This then has a two-fold effect. Firstly it increases η as can be seen from (6.2) and secondly f also increases as can be seen by increasing $\sigma_a(U)$ in (6.12). The value of η increases more rapidly than f. For example, for $E = 2$ $\eta = 1{\cdot}632$ compared with $1{\cdot}34$ for natural uranium, whereas taking the case previously quoted of graphite to uranium atoms f increases from $0{\cdot}84$ to $0{\cdot}89$. Then in this case, assuming p remains at the value of $0{\cdot}70$, k will become $1{\cdot}02$, and so a chain reaction could be maintained.

Table 6.2 quotes values of η and $\sigma_a(U)$ for various values of E. It also illustrates the increase in f with E, taking a value of f of $0{\cdot}9$ for natural uranium and the consequent increase in ηf.

E	η	$\sigma_a(U)$ in barns	f	ηf
1	1·34	7·67	0·900	1·21
2	1·63	12·6	0·937	1·53
3	1·76	17·5	0·954	1·68
10	1·98	52·0	0·984	1·95
20	2·03	101	0·992	2·02
139	2·08	687	0·999	2·08

Table 6.2 ***variations of parameters with uranium enrichment***

2. The bare reactor

The next step is to consider a finite system and to find the neutron flux distributions as a function of position. The simplest case to consider is that of a single multiplying medium assumed homogeneous and of uniform composition. It will be supposed that the medium is of such a size and the value of k sufficient to make the bare reactor, as we shall call it, critical.

There are two basic differential equations which give the spatial distribution of the neutrons—one for the slowing-down neutrons and one for the thermal neutrons.

In a finite capturing medium the slowing-down density in the steady state q_s is given by (5.24) and (5.25) namely

$$q_s = pq \tag{6.13}$$

$$\nabla^2 q = \frac{\partial q}{\partial \tau} \tag{6.14}$$

The thermal neutron flux ϕ is given by the usual diffusion equation (see equation (2.45))

$$\frac{\lambda_t}{3}\nabla^2\phi - \Sigma_a\phi + S = 0 \tag{6.15}$$

where S is the source of thermal neutrons.

Now the source of thermal neutrons is those neutrons which slow down to thermal energies and avoid resonance capture. And from (6.13) this is equal to

$$pq(\tau_{th}) = pq(L_s) \tag{6.16}$$

so (6.15) becomes

$$\frac{\lambda_t}{3}\nabla^2\phi - \Sigma_a\phi + pq(L_s) = 0 \tag{6.17}$$

If q is now assumed to be a product of two functions, one, $X(r)$, depending on the space variables which will be characterised by r, and the other, $Y(\tau)$, depending on τ. q can then be written

$$q = X(r)Y(\tau) \tag{6.18}$$

and if this is substituted into (6.14) it gives

$$\frac{\nabla^2 X(r)}{X(r)} = \frac{1}{Y(\tau)}\frac{dY(\tau)}{d\tau} \tag{6.19}$$

Now the left hand side is a function of the space co-ordinates only and the right hand side of τ only. Thus each side is a constant and if this is put equal to $-B^2$, then from (6.19)

$$\frac{1}{Y(\tau)}\frac{dY(\tau)}{d\tau} = -B^2 \tag{6.20}$$

so that integrating this leads to

$$Y(\tau) = Ae^{-B^2\tau} \tag{6.21}$$

where A is an arbitrary constant. The minus sign with B^2 is chosen for convenience as the slowing-down density decreases with increasing τ. Then substituting from (6.21) and (6.18) into (6.16) gives

$$S = pX(r)Ae^{-B^2 L_s^2} \tag{6.22}$$

Also from (6.19) and (6.20)

$$\nabla^2 X(r) + B^2 X(r) = 0 \tag{6.23}$$

and substituting from (6.22) into (6.17) and eliminating $X(r)$ by using (6.23) leads to

$$\nabla^2\phi + B^2\phi = 0 \tag{6.24}$$

* Using 4·8 barns and 5 millibarns respectively for the scattering and absorption cross-sections of graphite

which is the equation for the thermal neutron flux as a function of the space co-ordinates.

There is a most important consequence of this picture of neutron behaviour in that when the reactor is critical the constant B^2 can be expressed in terms of the values of k, L^2 and L_s^2 for the medium.

Consider first, $q(0)$, the value of the slowing-down density for neutrons of zero age, that is fission neutrons. The fission neutrons are formed by absorbing thermal neutrons in the fuel, consequent fission and then subsequent fast fission. So at any point per cm^3 of the system

$\phi\Sigma_a$ neutrons are absorbed

$f\phi\Sigma_a$ neutrons are absorbed in the fuel

$\varepsilon\eta_t\phi f\Sigma_a$ fission neutrons are produced

and so $q(0)$ must be given by

$$q(0)=\varepsilon\eta_t f\phi\Sigma_a \tag{6.25}$$

which from (6.18) and (6.21) putting $\tau = 0$ can be written

$$q(0)=AX(r) \tag{6.26}$$

Now from (6.18) and (6.21) putting $\tau = L_s^2$

$$q(L_s)=AX(r)e^{-B^2L_s^2} \tag{6.27}$$

and using (6.25) and (6.26) this becomes

$$q(L_s)=\varepsilon\eta_t f\phi\Sigma_a e^{-B^2L_s^2} \tag{6.28}$$

This substituted into (6.17) using (6.18) and (6.24) and cancelling ϕ yields the equation

$$ke^{-B^2L_s^2}=1+\frac{\lambda_t}{3\Sigma_a}B^2 \tag{6.29}$$

But $$\frac{\lambda_t}{3\Sigma_t}=L^2 \qquad \text{(see (2.48))}$$

and so

$$k=e^{B^2L_s^2}(1+B^2L^2) \tag{6.30}$$

The importance of this equation lies in the fact that for a given medium the values of k, L^2 and L_s^2 can be determined and then (6.30) enables B^2 to be found. In other words B^2 is a function of the materials of the system and their arrangement in the system, and as calculated from (6.30) is independent of the size of the system.

Now consider equation (6.24). It is of such a type that for a given size of system there are a series of values of B^2 depending on the size of the system which enable the equation to be satisfied, and if the system is critical then only the solution with the smallest value of B^2 appears. Furthermore, because this value of B^2 determines the curvature of the flux, it is called the *buckling*.

Then when B^2 is determined from (6.24) because it depends on the size of the system it is called the *geometrical buckling*, B_g^2. When, however, B^2 is found from (6.30) and depends on the material of the system it is called the *material buckling*, B_m^2.

However, for a critical reactor the thermal neutron flux distribution is given by (6.24) with a uniquely determined value of B_g^2 which if the system is critical must also equal B_m^2 as there is nothing in the analysis between (6.13) and (6.30) to differentiate between the two different bucklings. So for a critical reactor

$$B^2=B_g^2=B_m^2 \tag{6.31}$$

3. Neutron leakage

We have seen that to maintain a chain reaction in an infinite system requires that $k = 1$. Because in a finite system some neutrons will inevitably leak out of the system in this case k will have to be greater than unity to make up for this loss. The next problem then is to find out what fraction of the neutrons leak out when slowing-down and what fraction leak out when diffusing.

From (6.18) and (6.21)

$$\frac{q(L_s)}{q(0)}=e^{-B^2L_s^2} \tag{6.32}$$

This equation states that the ratio of the slowing-down density of neutrons of age $\tau_{th}=L_s^2$, that is, of neutrons just becoming thermal, to the slowing-down density of fission neutrons is $e^{-B^2L_s^2}$. This means that a fraction of neutrons $e^{-B^2L_s^2}$ become thermal neutrons and so a fraction

$$1-e^{-B^2L_s^2} \tag{6.33}$$

must leak out when slowing down. This result it should be noted is independent of the position.

Now for the thermal neutrons the leakage per unit volume per second at any point is (see (2.39))

$$-\frac{\lambda_t}{3}\nabla^2\phi \tag{6.34}$$

or using (6.24) is

$$\frac{\lambda_t}{3}B^2\phi \tag{6.35}$$

and the number absorbed per unit volume per second at any point is

$$\Sigma_a\phi \tag{6.36}$$

Thus the fraction of thermal neutrons remaining in the system is

$$\frac{\Sigma_a\phi}{\Sigma_a\phi+\frac{\lambda_t}{3}B^2\phi}=\frac{1}{1+B^2L^2} \tag{6.37}$$

and again this is independent of position.

Then from the definition of k, one thermal neutron results in k fast neutrons. After slowing down $ke^{-B^2L_s^2}$ neutrons remain in the system. Then of these a fraction $1/1+B^2L^2$ leak out as thermal neutrons and so finally

$$\frac{ke^{-B^2L_s^2}}{1+B^2L^2} \tag{6.38}$$

thermal neutrons are available to carry on the chain reaction. This quantity is called the effective multiplication constant k_{eff}, so that

$$k_{eff}=\frac{ke^{-B^2L^2}}{1+B^2L^2} \tag{6.39}$$

If the reaction is to be critical then we need one thermal neutron to carry on the reaction, so then for a critical reactor

$$k_{eff}=1 \tag{6.40}$$

and (6.39) then reduces to (6.30).

Next month's instalment will deal with conversion factors, neutron balance and the critical size of a bare reactor

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W.D.

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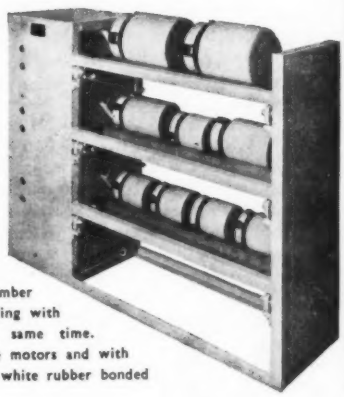

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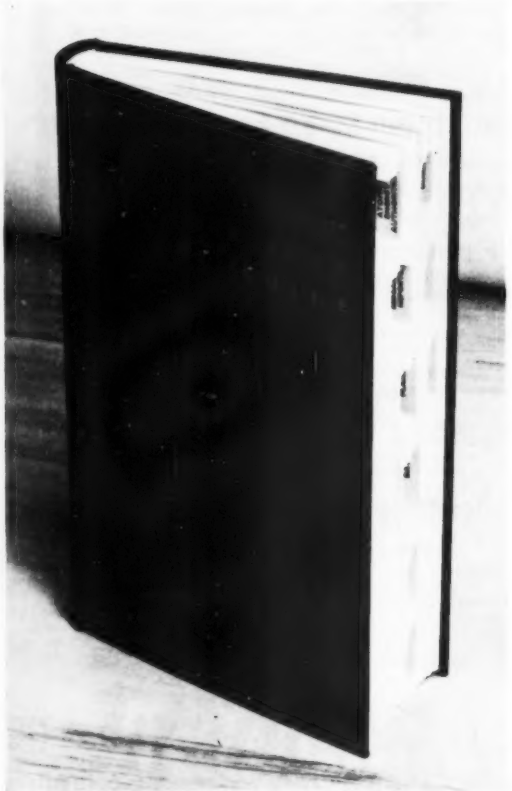

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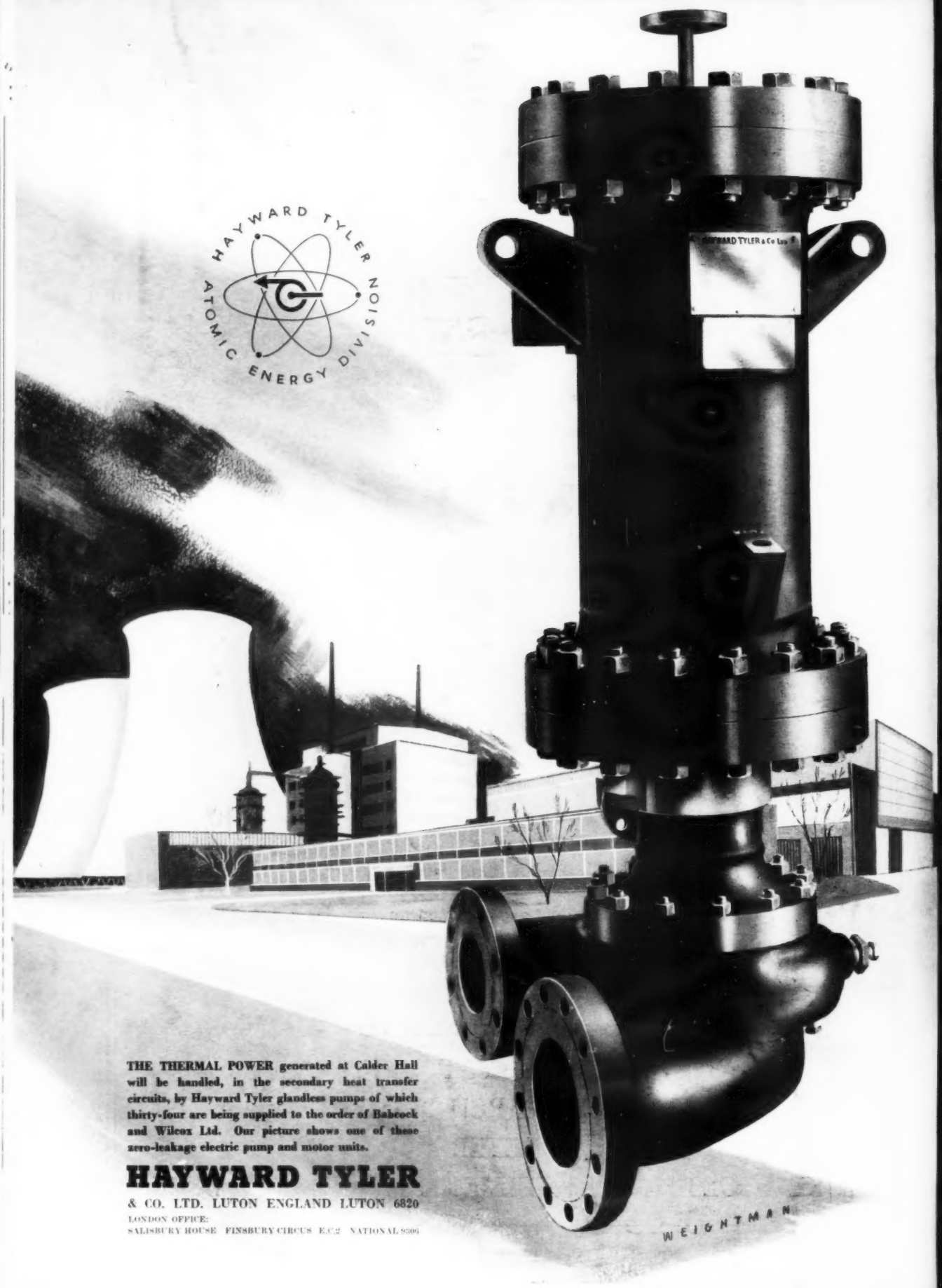

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